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ALBERTA MODERN AIRSHIP STUDY

FINAL REPORT

JUNE 1978

PREPARED FOR THE ALBERTA MINISTRY OF TRANSPORTATION

BY

GOODYEAR AEROSPACE CORPORATION Akron, Ohio

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ALBERTA MODERN AIRSHIP STUDY
FINAL REPORT

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June 1978

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PREPARED FOR THE ALBERTA MINISTRY OF TRANSPORTATION
BY
GOODYEAR AEROSPACE CORPORATION

.ID 71)
REF: EOI 380

FOREWORD

Goodyear Aerospace Corporation has conducted a study for the Alberta Transportation Ministry to define the potential of modern airship vehicles in meeting current and projected transportation needs of Alberta, Alberta-based industries and other portions of Canada with similar transportation requirements.

Goodyear wishes to acknowledge the significant contribution of the Alberta Transportation Ministry throughout the study effort. Many other government agencies and industrial organizations within Canada also provided valuable assistance during the study effort and their support is greatly appreciated.

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CONVERSION TABLE - METRIC TO ENGLISH UNITS

AREA

1 square kilometre (km^2) = 0.386 square miles

DISTANCE

1 kilometre (km) = 0.540 nautical miles (nm)

1 km = 0.621 statuate miles (sm)

LENGTH

1 metre (m) = 3.281 feet (ft)

MASS

1 kilogram (kg) = 2.205 pounds (lbs)

1 kg = 0.0011 tons

MASS PER UNIT LENGTH

1 kg/m = 0.672 pounds/foot (lbs/ft)

MASS PER UNIT VOLUME

1 kilogram/cubic metre(kg/m^3) = 0.062 pounds/cubic foot(lbs/ft^3)

TEMPERATURE

1°Celsius (°C) = (°F - 32) x 5/9

VELOCITY

1 kilometre/hour (km/h) = 0.540 knots (kt)

1 km/h = 0.621 miles/hour (mph)

VOLUME

1 cubic metre (m^3) = 35.315 cubic feet (ft^3)

1 m^3 = 423.776 board feet

NOMENCLATURE

AFCS	Automatic Flight Control System
ASkm	available seat kilometer
ASnm	Avail Seat Nautical Mile
CTOL	Conventional Take-Off and landing
DEG	Degrees of Angle, (°)
DOC	Direct Operating Cost
DOF	Degrees of Freedom
FBW	Fly-By-Wire
Hercules	Common Name for Lockheed Aircraft [C-130]
HLA	Heavy Lift Airship
IOC	Indirect Operating Cost
MCA	Modern Conventional Airship
MCM	Millions of Cubic Meters
MPH	Miles per Hour
NASA	National Aeronautics & Space Administration
nm	Nautical Miles
PHS	Precision Hover Sensor
RDT&E	Research, Development, Test and Evaluation
ROI	Return on Investment
ROW	Right-of-Way
RPM	Revolutions per Minute
TOC	Total Operating Cost
TOC/Akg-km	Total Operating Cost per Available Kilogram Kilometer
TOC/ASnm	Total Operating Cost per Available Seat Nautical Mile
TOC/ASkm	Total Operating Cost per Available Seat kilometer
TS	Transportation System

NOMENCLATURE [CONT'D]

U.L.	Useful Load
V/STOL	Vertical/Short Take-Off and Landing
VTOL	Vertical Take-Off and Landing

1.0 SUMMARY

The application of modern airships in meeting current and projected industrial transportation needs of Alberta and Alberta-based industries has been investigated. Based upon the study results presented herein, it is concluded that modern airships offer significant economic advantage as an adjunct to the developing transportation system within the study area. The study results also indicate that the establishment of an airship operating company (rental service) is both essential to the introduction of airships in the study area and is a viable business opportunity for the private sector.

Heavy Lift Airships (HLA's) which combine proven airship and helicopter components and technology, and modern conventional airships (both rigid and non-rigid) have been considered during the study. A range of HLA's, varying in useful load capability from 45,372 to 142,468 kg (50 to 157 tons*) and modern conventional non-rigid airships varying in useful load capability from 7,260 to 22,686 kg (8 to 25 tons), have been investigated. A large modern conventional rigid airship with a useful load of 151,543 kg (167 tons) has also been evaluated.

HLA's considered during the study are shown to be economically viable in a wide variety of construction industry applications. These applications involve both the movement of construction equipment and project operating equipment. Other economically viable HLA applications reported herein include the transport of

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*Refer to Page x for conversion to English units for Figures and Tables prefabricated structures, transport of oil and gas drilling equipment, and uses within the forestry industry (both fire fighting and logging).

Modern conventional non-rigid airships are shown to have economically viable applications in the transport of both cargo and personnel. Although supporting data has not been developed at this point, personnel within the surveying industry in Canada suggest that a small modern conventional non-rigid airship (useful load of 7,260 kg or eight tons) is economically attractive in a multipurpose survey related capacity. There also appears to be coastal patrol applications for the small non-rigid airship in Canada.

Large non-rigid airships, 22,686 kg (25 tons), have economically viable applications in moving prefabricated structures, goods and equipment in priority situations as well as considerable application in the transport of personnel.

Large rigid airships have economically viable applications in moving prefabricated structures, goods and equipment to remote areas. The large rigid appears economically preferable to trucks and other special purpose aircraft (e.g. helicopters, Hercules).

Airships are operationally compatible with the Canadian environment and can be effectively operated in the many remote regions of the country. In comparison with previous airship configurations and operations, modern technology significantly enhances the application of airships in the study area due to: (1) improved controllability in hover and low speed flight, (2) improved structural efficiencies while also resulting in greater structural integrity, (3) enormous improvements in propulsion systems, (4) improved avionics, and (5) an improved ability to forecast and communicate weather information.

Development requirements are presented for the modern airships considered. The development of the airships considered can proceed immediately with high technical confidence. Airships can be introduced in the study area in the near term given sufficient development priority. As in the introduction of any new product, successful demonstration is a prerequisite to acceptance. User confidence as well as regulatory agency acceptance are essential elements in the plan to introduce an airship transport service. It is reasonably clear that the private sector will not substantially underwrite the demonstration of a modern airship transportation system. Governmental support appears essential in this area.

Applications for the modern airships considered herein are not unique to the study area. Worldwide there appears to be a demand for significantly greater numbers of vehicles than in the study area. The expanded market possibilities attendant with this factor accentuates the already strong entrepreneurial interests found in the private sector within Alberta in terms of operating an airship transport service.

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1.1 Introduction

The importance of an adequate transportation system in a modern progressive state is obvious. The sparsely populated regions of Alberta and the remainder of the Canadian North find themselves in a unique situation where previously low traffic demands have not necessitated the typically well developed Transportation System (TS) found in the more heavily populated parts of Canada. Current and projected needs to develop this resource-rich area of Canada focus attention on the developing nature of the TS.

Projects in the Canadian North tend to be widely separated adding to the cost of a permanent highway/rail infrastructure. Another aspect associated with many resource-related projects is that the operational life of the project, as in the case of remote mines, may only be 15 years.

The lack of a well developed TS (which typically requires a large population to support the associated large capital investment) keeps the traffic low thus discouraging economic growth and resource development. During the current study, the airship has been investigated as an approach that breaks this cycle and removes the near zero growth that can be associated with such a cycle. In this respect, the airship can be viewed from the standpoint of offering a flexible, interim system that permits development of an area, at an acceptable cost, to a population and economic level such that a permanent TS involving a large capital investment can be afforded when and where required.

The concept of the airship operating as a flexible interim transportation system can also provide Government transportation and environmental protection personnel with additional time to plan the most cost-effective, environmentally acceptable permanent system while providing a mechanism for permitting the economic development of an area.

In addition, the potential of the airship is explored herein, from the following standpoints:

(1) The development of remote sites either where permanent highways or railroads are not required on a traffic demand basis or where their construction would be extremely expensive due to difficult and changing soil conditions or environmental precautions that may be necessary;

(2) The direct competition with other special purpose aircraft (e.g., helicopters, Hercules) in the transport of cargo and passengers and truck transport of cargo;

(3) Short haul heavy lift transport requirements beyond current and projected helicopter lift capabilities that are currently accomplished by a combination of methods;

(4) Survey and coastal patrol applications.

1.2 Study Objectives

In summary form, the study objectives were to:

(1) Define the potential of modern airship vehicles in meeting current and projected transportation needs of Alberta, Alberta-based industries and other portions of Canada with similar transportation requirements; and

(2) Define a suggested approach and timetable for implementing an airship transportation service for those configurations showing sufficient economic potential.

1.3 Terms of Reference

(1) Mission Definition

Characterize current transportation need in terms permitting the synthesis of modern airship vehicles meeting these needs.

Project future transportation needs based upon expected industrial expansion.

(2) Vehicle(s) Definition

Synthesize modern airship vehicle(s) meeting the needs as established in Item (1). Vehicle(s) general arrangement(s) shall be produced defining the configuration(s) physically.

Define expected performance capabilities. Buoyant lift, propulsive lift, empty weight and similar descriptive data shall be provided.

(3) Operational Analysis

Conduct operational analysis based on Items (1) and (2) above. The operational analysis shall consider operational procedures, description of personnel requirements (ground and flight), interface with industrial equipment requiring transport, climatic conditions, mooring requirements, etc.

(4) Economic Analysis

Provide estimate of vehicle(s) acquisition cost and total operating cost based on Items (1), (2), and (3).

Establish economic competitiveness of vehicle(s) based on Items (1), (2), and (3).

Provide estimate based on Items (1), (2), and (3), of the number of vehicle(s) required to meet existing and projected transportation needs.

(5) Development/Production Schedules

Provide vehicle development schedules as appropriate.

Provide vehicle production schedules as appropriate.

(6) Documentation

Provide interim and final reports with the final report summarizing results of Parts One and Two of the study along with pertinent conclusions and recommendations.

Provide final briefing in Alberta relative to overall study results, conclusions, and recommendations.

Provide Executive Summary presentation materials relative to overall study results, conclusions, and recommendations.

1.4 Study Approach

1.4.1 Mission Definition

The primary objective of this study task was to identify transport applications to which airships are potentially suited and to gather sufficient data to permit the operational suitability and economic competitiveness of the airship to be evaluated in subsequent study tasks.

The identification of missions to which airships are, in fact, suited is solely a consideration of competitive economics once it is established that the airship can perform the mission from an operational standpoint. The economic and operational suitability of the airships were addressed as a separate task (see below) in the study.

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Several previous studies of this subject have been completed by Goodyear, e.g., Reference 1, and the results of these previous efforts provided a sound basis for initially identifying areas of potential economic competitiveness. The Alberta Transportation Ministry also provided reference material (References 2 through 20) that was very valuable in identifying the competitive nature of existing transportation modes in various sections of Canada.

Many of the transportation requirements that various industrial concerns face in Alberta and Canada are unique in that there are often cost factors associated with current transportation modes and techniques that would not be involved in shipment by airship. These factors include:

(1) Infrequent highway, rail and bridge facilities and therefore circuitous routing compared to the direct shipment by air.

(2) Seasonal bans thus reduced load capacities and scheduling that can lead to investment losses because of goods shipped early to avoid bans as well as warehousing costs in some cases.

(3) Seasonal bans necessitating movement of heavy construction equipment at inopportune times to avoid entrapment for extented periods of time. These inopportune movements reduce construction season durations etc., resulting in increased project costs.

(4) Low speed on winter and bush roads. These low speeds increase overland transport costs and can lead to investment cost losses when considering the span time required to move in quantities of material or goods.

(5) Short barging and winter road transport season which often necessitate goods being shipped months in advance resulting in investment and warehousing costs.

(6) The necessity of shipping equipment at low levels of assembly because of size and/or weight limitations on existing railroads/highways resulting in large in-field assembly requirements under inefficient conditions at high labor rates.

(7) Environmental damage and subsequent restoration costs and project delays associated with regulatory agency studies and approvals.

(8) Intermodal changes.

Because of factors such as the above, Goodyear deemed it essential that first-hand knowledge of the transportation problems of representative industries within Alberta and other portions of Canada be obtained. As a result personal surveys were conducted with approximately 15 different companies to ascertain:

(1) A description of the nature of their current approach to their transportation requirements;

(2) Specific details on the type, size, weight, quantity and frequency of shipments, stage lengths, placement accuracy requirements, etc., associated with current transport requirements;

(3) Personnel transport requirements;

(4) A best estimate of the cost of current transportation costs, including an understanding of the magnitude of the attendant cost factors as summarized above;

(5) An understanding of the operational suitability of modern airships to their transportation needs;

(6) An understanding of their desire to own and operate or rent an airship transport service;

(7) An understanding as to whether there would be any reticence on their part, for whatever reason, in using an airship service if it improved the economics of their current transport operations or resulted in attendant economic benefits.

(8) An understanding of the demand for airship services applicable to their industry based upon preliminary estimates for the cost of the service.

Future transportation demands are based upon projected industrial expansion as reported in reference material (References 2 and 3) provided by the Alberta Transportation Ministry plus an estimate of the number of devices that the market area examined can currently support. In that respect, there appears to be a consensus of opinion that the development activity in the area is expected to continue to expand and that improved transportation capabilities would have a favorable impact upon projected expansion. All projections must, either explicitly or implicitly, consider an anticipated overall economic condition (for the area, nation, or perhaps world) for the projection period. Projections herein assume no change in the economic conditions that currently exist in the area under consideration.

The details, results and conclusions of the mission definition effort are reported in Section 2.1 of this report.

1.4.2 Vehicle Definition

Based upon a compilation of the data from the industry surveys and other available resource data on transportation requirements in the study area and relevant technical and operational considerations the following were defined:

(1) Types of airship configurations meeting existing or projected transportation needs;

(2) Major physical characteristics; and

(3) Major performance characteristics of each configuration.

1.4.3 Operational Analysis

Based upon the results of the mission and vehicle definition tasks an operational analysis was performed. Past airship operational experience was considered with respect to the operational concepts postulated for the configurations identified above and basic differences defined and analyzed. The environment in which the airships will be operating were reviewed and again comparisons to the environments in which past airships have operated were made and differences analyzed.

Basing requirements (permanent and remote), crew requirements (flight and ground), and the management and administrative personnel required to support a rental service operation were identified. For neutrally-buoyant modern conventional airships, methods were postulated for off-loading payload and on-loading ballast at remote sites.

Based upon the operating concepts postulated for each configuration, the climatic conditions of the study area, and utilization trends for heavier-than-aircraft, the range of expected annual utilizations were developed for each vehicle type to support the economic analysis described below.

1.4.4 Economic Analysis

An analysis was completed of the Total Operating Cost (TOC) of the configurations identified as having potential application in meeting the transportation needs of the study area. Details of the methodology used in arriving at the TOC for the various configurations as well as the details of the analysis are provided in Section 4.2 of this report.

Based upon survey results it is obvious that few if any industrial concerns or consortiums would own and operate an airship service. There was almost unanimous agreement among those surveyed that a rental service would have to be available as in the case of helicopters, fixed wing aircraft, trucks, heavy equipment, etc. As a result Goodyear supported this portion of the study effort by undertaking the development of a model to describe an airship operating company and associated financial considerations. Thus, an estimate of the rental price for the subject airship transport services was calculated based on a reasonably attractive Return On Investment (ROI), a reasonable level of equity by the rental service company owners, and a currently representative interest rate on the monies borrowed to capitalize the venture. Details of this additional effort by Goodyear is summarized in Appendix A to this document.

Once the rental service price was determined for the various configurations under evaluation several specific economic case studies were completed to indicate the cost benefit that the airship offers over current transport techniques. Often many of the cost factors identified in Section 1.4.1 of this report were necessarily considered in these economic comparisons. Based on: (1) the results of the case studies and the degree of economic leverage that the airships offered; (2) the transport demand information secured during the surveys; and (3) demand data available from reference material, an overall projection was made as to the number of airships of each configuration that could effectively be employed in Canada.

1.4.5 Vehicle Availability

In support of the economic analysis, and as an element in the analysis of matching availability with market demand, vehicle availability schedules were developed. Vehicle Research, Development, Test and Evaluation (RDT&E) requirements and manufacturing schedules were explicitly defined as a part of this activity.

2.0 STUDY RESULTS

2.1 Mission Definition

2.1.1 General

As noted previously, both available reference documents on the transportation needs of the study region as well as personal surveys were used to define potentially competitive missions for airships. For two reasons which are discussed below, it was considered prudent to expand the market analysis to permit an estimate of the total world market needs for the various configurations being considered in Canada.

Firstly, the price of an airship rental service is significantl dependent upon the quantity of vehicles manufactured for reason discussed in Section 4.2. Thus, to provide a realistic estimate of the magnitude of airship transportation service costs, Goodyear has included herein an estimate of world demand based upon corporately sponsored market analyses in other areas of the world. A second reason for highlighting

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world market possibilities is the fact that entrepreneurial interest often extends beyond national boundaries.

2.1.2 Airship Applications

Table I summarizes the name, location, and general area(s) of activity of the organizations surveyed to date.

Table II summarizes the types of applications emerging from the mission definition task to which airships appeared potentially well suited based upon survey results. These specific applications were then addressed (where possible) on a case by case benefit basis during the economic analysis task (see Section 4.4). Table III illustrates physical and weight characteristics of representative heavy components and equipment that are considered for transport in the ensuing case studies. Table IV summarizes the case studies actually reported in Section 4.4.

2.1.3 Current Transport Costs

The current cost of meeting transportation needs, which was again gathered during the surveys and through available reference material, published rates, etc., is presented as needed in the case study analysis of Section 4.4 of this report.

2.2 Vehicle Definition

2.2.1 General

There are many different air transport requirements currently being served by a variety of heavier-than-air aircraft. Similarly, different types of airships have been considered herein for meeting the various types of transport needs of the study area.

In addition to different types of airships being considered during the study, different sizes of the same type of vehicle were also considered. The following paragraphs offer the rationale for the sizes selected for consideration.

TABLE I - ORGANIZATIONS SURVEYED

ORGANIZATION	LOCATION	TYPE OF INDUSTRY
Loram, Ltd.	Calgary	Construction (General)
Bechtel, Inc.	Edmonton San Francisco	
SNC Group	Montreal	
Brown & Root, Inc.	Houston	
Flour, Inc.	Houston	
Morrison & Knudeson, Inc.	Boise, Idaho	
Seward, Inc.	Kittery, Maine	
Hoosier Construction Co.	Columbus, Ohio	
Foothills Pipeline Co., Ltd.	Calgary	Oil and Gas (Well/Line Construction/Operation)
Polar Gas	Toronto	
Parker Drilling Co.	Tulsa, Oklahoma	
(Loram) *		
(Brown & Root)		
(Bechtel)		
(SNC)		
(Flour)		
Dome Petroleum, Ltd.	Calgary	
AMAX Northwest Mining Co., Ltd.	Golden, Colorado	Mining Industry (Construction & Transport of Concentrate and Operating Personnel)
Texas Gulf, Inc.	Denver	
(Loram)		
(Bechtel)		
(SNC)		
North Canadian Forest Industries	Grand Prairie, Alberta	Forestry Industry (Logging/Fire Fighting)
Alberta Department of Energy & Natural Resources	Edmonton	
Forest Engineering Institute of Canada	Vancouver	
Council of Forest Industries of British Columbia	Vancouver	
North Canadian Power	Whitehorse	Power Generation Industry (Construction/Operation)
Evergreen Helicopters Inc.	Atlanta	
(Seward)		
(Hoosier Construction Co.)		
(SNC Group)		
(Bechtel)		
Canadian Engineering Surveys Co., Ltd.	Edmonton	Survey Industry
ATCO Structures, Ltd.	Calgary	Prefabricated Structures (Transport)
Union Mechling Corp.	Houston	Rigging Industry (Movement of Heavy/outsized Loads)
Williams Crane & Rigging, Inc.	Richmond, Virginia	

* Parenthesis indicates company listed previously under general heading of Construction Industry

TABLE II - APPLICATIONS EMERGING FROM MISSION DEFINITION TASKS

Type of Industry	Applications
Construction Industry (General)	Extension of winter and summer construction season in Canada Movement of heavy equipment over river crossings, difficult terrain, swamps, deserts, etc. Emergency movement of heavy equipment (construction and operating) Movement of heavy equipment termination of rail and highway access and harbor to construction site Off-loading of ships in areas lacking deep water port facilities Movement of operating equipment to site at higher level of assembly than currently practical Reduction in project span time by early movement of construction equipment to project site Reduced need for heavy haul roads and barge/ship off-loading facilities On-site construction support Reduced construction equipment inventory General transport of construction materials under special conditions Reduction/elimination of environmental impact and restoration requirements Movement of personnel involved in construction effort
Oil and Gas (Well/Line Construction/Operation)	Extension of winter and summer construction seasons in Canada Movement of heavy construction equipment over river crossings, difficult terrain, swamps, deserts, etc. Movement of heavy construction equipment along ROW under special conditions Movement of modularized compressor station equipment (larger than is practical over the road) Movement of pre-assembled valve assemblies Emergency repair of pipe lines (break and reduced thruput) Transport of pipeline construction materials under special conditions Movement of campsite structures and equipment Reduction of construction and operating equipment inventories both during construction and operation Reduction in number of construction sites along ROW Movement of drill rigs and drilling supplies into remote areas Movement of exploration equipment Reduction/elimination of environmental impact and restoration requirements
Mining Industry	See applications from Construction Industry (General) above Transport of concentrate from remote mine sites Transport of mine operating personnel to and from mine site Mineral exploration
Forestry Industry	Logging Fire fighting (chemical treatment and movement of heavy equipment to create fire breaks)
Power Generation Industry	See applications from Construction Industry (General) above Installation of large pre-assembled transmission line towers
Survey Industry and Coastal Patrol	Land surveys, seismic surveys, gravity surveys, magnetic surveys, oceanographic surveys, off-shore drill ship positioning, fish tracking, aerial photography
Prefabricated Structures	Transport and placement of structures
General Transport	Competition with existing air and highway transport modes in areas where permanent infrastructure is under development

TABLE III TYPICAL CONSTRUCTION AND OPERATING EQUIPMENT

PAYLOAD	UNIT WEIGHT RANGE (KG)	MAXIMUM DIMENSIONS (M)		
		LENGTH	WIDTH	HEIGHT
TRACTORS/DOZERS	40,824 - 81,648	19.8	3.7	4.3
BACKHOES	40,824 - 113,400	36.6	5.5	4.6
CRANES	40,824 - 117,936	56.7	4.6	4.6
DITCHERS	68,040	22.9	3.7	4.6
DRAG LINES	68,040 - 113,400	33.5	3.7	4.6
HAULERS	45,360 - 136,080	15.2	6.4	5.5
LOADERS	18,144 - 45,360	-	-	-
SCRAPERS	22,680 - 68,040	-	-	-
PIPE LOADER	36,288	21.3	3.4	5.2
PIPE LAYER	56,246	19.8	3.7	4.6
FORKLIFT	36,288	-	-	-
TRANSFORMERS	45,360	-	-	-
TRANSMISSION TOWERS	18,144 - 45,360	45.7	12.2	12.2
COMPRESSORS	27,216 - 45,360	-	-	-
VALVES	27,216 - 45,360	-	-	-
VESSELS/TANKS/BOILERS	45,360 - 122,472	50.3	7.0	7.0
CRUSHERS	40,824 - 99,792	30.5	3.7	4.6
PREFAB STRUCTURES	36,288	28.	4.3	3.4
BRIDGE GIRDERS	22,680 - 68,040	30.5	-	-
PUMPS	40,824	-	-	-

TABLE IV - SUMMARY OF CASE STUDIES

Industry	Application	Vehicle
General Construction Industry	Early Movement of Construction equipment to remote projects	HLA
Oil and Gas Industry	Movement of construction equipment across rivers (two cases)	HLA
	Extension of winter construction season (two cases)	HLA
	Emergency repair of pipeline (two cases)	HLA
	Modular construction of compressor stations	HLA
	Movement of construction equipment between Arctic Islands (two cases)	HLA
	Oil and gas drilling in remote areas	HLA
Power Generation Industry	Erection of power transmission line towers (two cases)	HLA
Mining Industry	Movement of personnel (two cases)	ZPG-X-5K
	Movement of Concentrate	Rigid airship
Forest Industry	Fire fighting	HLA
	Logging	HLA
Prefabricated Structures	Transport of structures (4 cases)	HLA ZPG-X-3W -Rigid
General Transport	Competition with trucks operating over winter and all-weather roads	HLA ZPG-X-3W
	Competition with various aircraft	Rigid

(1) Two sizes of non-rigid airships have been considered primarily because there is a commonality of interest in these general sizes of vehicles on a worldwide basis (commercial and military). This commonality of interest significantly reduces the development costs to any single user because of a large amortization base and as a result appreciably increases the probability of the vehicle being developed. Secondly, a larger number of vehicles produced reduces the vehicle acquisition cost because of "learning curve effects".

(2) Only one size of rigid airship has been considered. Again, this relates to the commonality of interest and reduced vehicle acquisition cost resulting as production quantity increases.

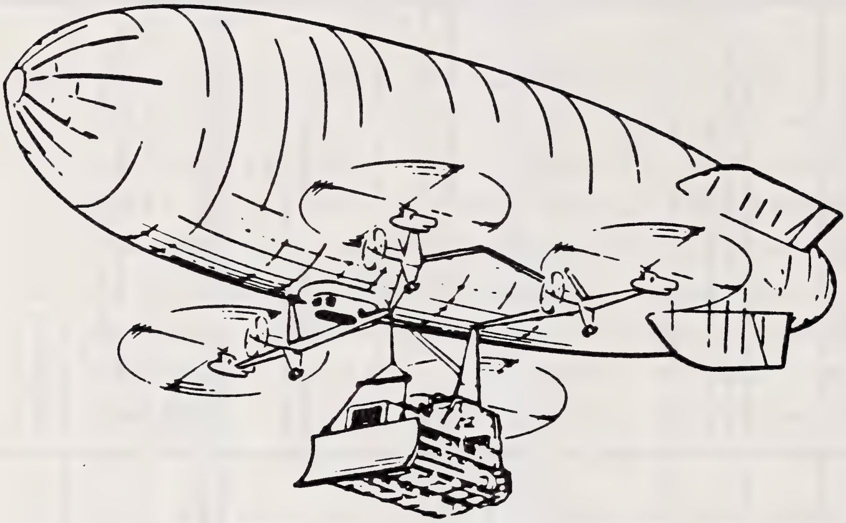
(3) A range of sizes of heavy lift airships has been considered during this study. The upper limit of this range was based upon a four-rotor configuration using what was estimated to be the maximum rotor diameter, disc loading, etc., reasonable for today's technology. This resulted in a maximum useful load on the order of 1,452 kg (160 tons). Use of a rotor system that provides equal amounts of positive and negative thrust permits an approximate two-fold increase in useful load. This subject is discussed further in Section 2.2.3.1 of this report.

Table V summarizes, by industry, the type and size of airships considered for meeting the applications identified in Table II above.

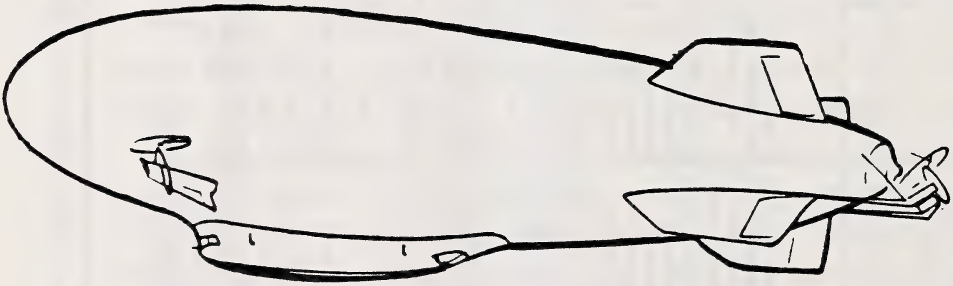
Figure 1 illustrates the major physical attributes of the airship configurations identified in Table V.

TABLE V - SUMMARY OF CONFIGURATIONS CONSIDERED

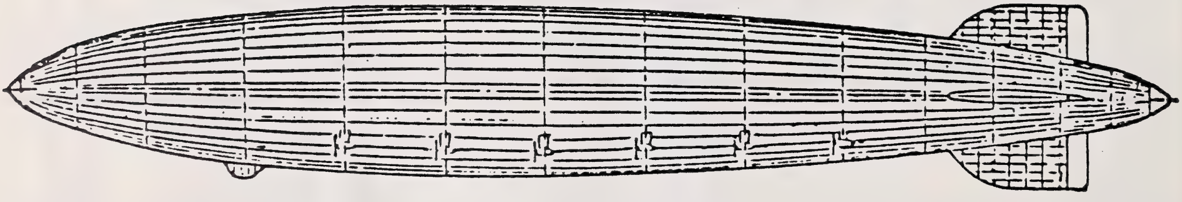
Type of Industry	Type of Construction	Payload (kg)	Endurance and/or Range (Unrefueled)	Ferry Range (Unrefueled) (km)	Maximum Useful Load (kg)	Cruise Speed (km/h)	Comments
General Construction	Heavy Lift Airship (HLA)	36,288 - 136,080 (VTOL)	4 hrs flight time at max payload	3704-5556	45,300 - 158,760 (VTOL)	148	Study results suggest current market could support two sizes: (1) Useful Load = 45,360 kg (2) Useful Load = 90,720-113,400 kg
		136,080 - 1,088,640 (VTOL)	Same as above	3704-5556	158,760 - 1,360,800 (VTOL)	148	Demand may eventually justify development of these large vehicles.
	Modern Conventional Airships Non-Rigid (ZPG-X-3W)	18,144 kg (VTOL) at 741 km	3700-5552 km Dependent upon payload and cruise speed	3704-5556 Dependent upon cruise speed	18,144 (VTOL) 22,680 (CTOL)	148	Primary market is movement of cargo to remote areas/projects where roads, airstrips, waterways do not exist.
	Rigid $V=3.11\times10^5 m^3$	133,358 kg at 1852 km 115,214 kg at 3704 km	Several thousand km dependent upon payload and cruise speed	Several thousand km dependent upon cruise speed	151,502 (VTOL)	185	Same as above
Oil & Gas	Heavy Lift Airships	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY (USEFUL LOAD = 90,720-113,400 kg)					
	Modern Conventional Airships Non-Rigid	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					
	Rigid	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					
Mining	Heavy Lift Airship	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					
	Modern Conventional Airships Non-Rigid (ZPG-X-5K)	7,530 kg (VTOL) at 741 km	2778-4625 km Dependent upon payload and cruise speed	2778-7408 km Dependent upon cruise speed	9,618 (CTOL)		Primary application is movement of mine operating personnel.
	Rigid	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					Application is transport of concentrate
Forestry	Heavy Lift Airship	38,102 kg (VTOL)	4 hrs flight time at max payload	3704-5556	45,360 (VTOL)	148	Applications are fire fighting and logging.
Surveying & Coastal Patrol	Modern Conventional Airship (ZPG-X-5K)	SAME AS FOR THE MINING INDUSTRY					Applications are: (1) Multi purpose surveying functions (2) Protection of 370 km economic limit
Prefabricated Structures	Heavy Lift Airship Modern Conventional Airship ZPG-X-3W Rigid	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					Applications are for transport of structures.
General Transport	Modern Conventional Airship (Rigid)	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					Application is competition with other transport modes



HEAVY LIFT AIRSHIP



MODERN CONVENTIONAL AIRSHIP (NON-RIGID)



MODERN CONVENTIONAL AIRSHIP (RIGID)

Figure 1 - Summary Of Configurations

2.2.2 Modern Conventional Airship (MCA)

MCA's are similar in appearance to prior airship configurations but differ from a functional, performance, economic, and safety standpoint substantially from previous airships because of:

(1) a better understanding of and more demanding structural requirements, particularly from an atmospheric disturbance standpoint

(2) much improved methods (computerized) for assuring structural integrity and high structural efficiency in all members

(3) enormous advances in propulsion system weight and reliability

(4) the use of vectored propulsion systems to provide hover capability, improved handling qualities at low speeds and improved ground handling operations

(5) improved ability to forecast and communicate weather information; and

(6) improved avionics.

It should be realized that the above do not represent a complete listing but rather a statement of the more important items that modern technology offers.

Historically, there have been two major classes of airships (rigids and non-rigids) identified primarily due to their structural character. The vast majority of non-rigid airships, as shown in Figure 2, have been constructed using

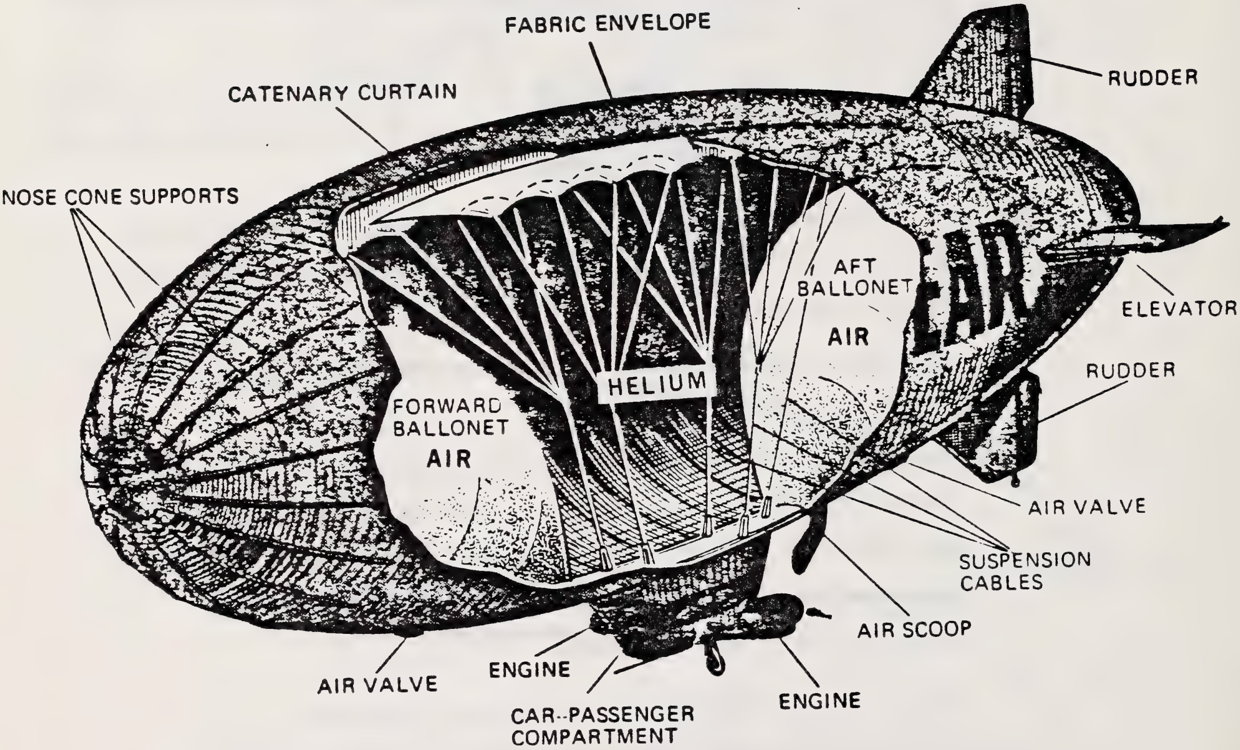


Figure 2 - Internal Arrangement Of Non-Rigid Airships

a pressure-stabilized fabric envelope. Metal-skinned pressure-stabilized non-rigid airships have also been demonstrated. Non-rigid airships have historically ranged in size from very small useful load capacities to the ZPG-3W which had a nominal gross lift of 42,184 kg (93,000 lbs). The ZPG-3W, shown in Figure 3, was built for the U.S. Navy by Goodyear in the late 1950's.

Based upon the application of modern technology, it appears that non-rigid airships several times larger than the ZPG-3W configuration are possible.

The largest airships built to date have been the rigid airships of the 1930 era such as the Graf Zeppelin, the Hindenburg, the Akron and the Macon. Goodyear built both the Akron and Macon (See Figure 4) airships for the U.S. Navy in the 1930 time frame. These ships were similar in size to the Hindenburg, the largest airship ever constructed, which was built in this same time period by the German Zeppelin Company.

There is a third historical class of airship, the semi-rigid, that represents somewhat of a hybrid between the rigid and non-rigid configuration.

In a recently completed study (Reference 1) for NASA-Ames, Goodyear thoroughly reviewed and documented relevant data on past airships, configurations and airship operations. During this same study Goodyear defined the benefits that modern technology can be expected to provide as well as comparison of the efficiencies of modern non-rigid and rigid airship configurations.

REF: EOI 380

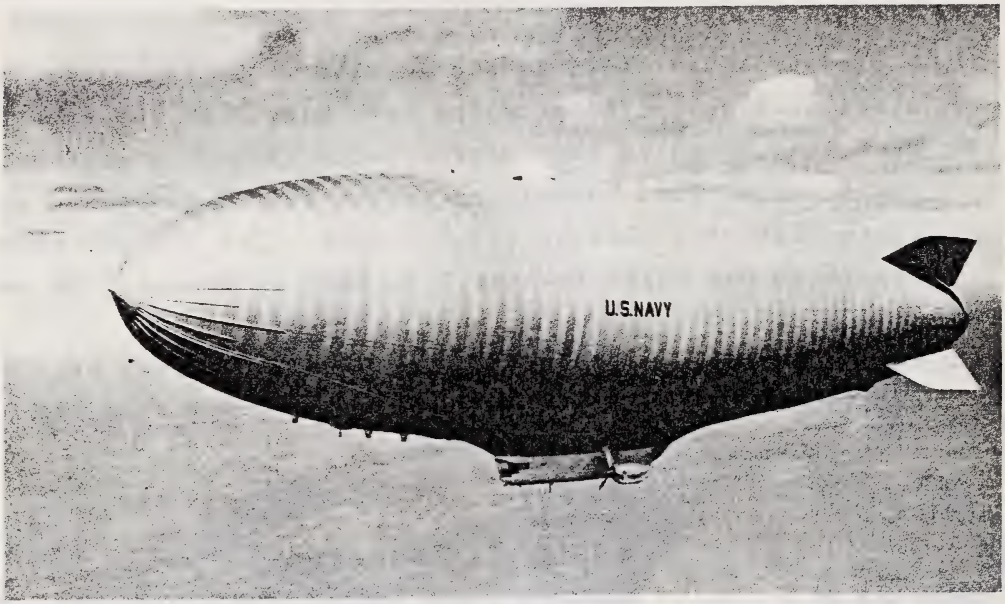


Figure 3 - ZPG-3W Airship

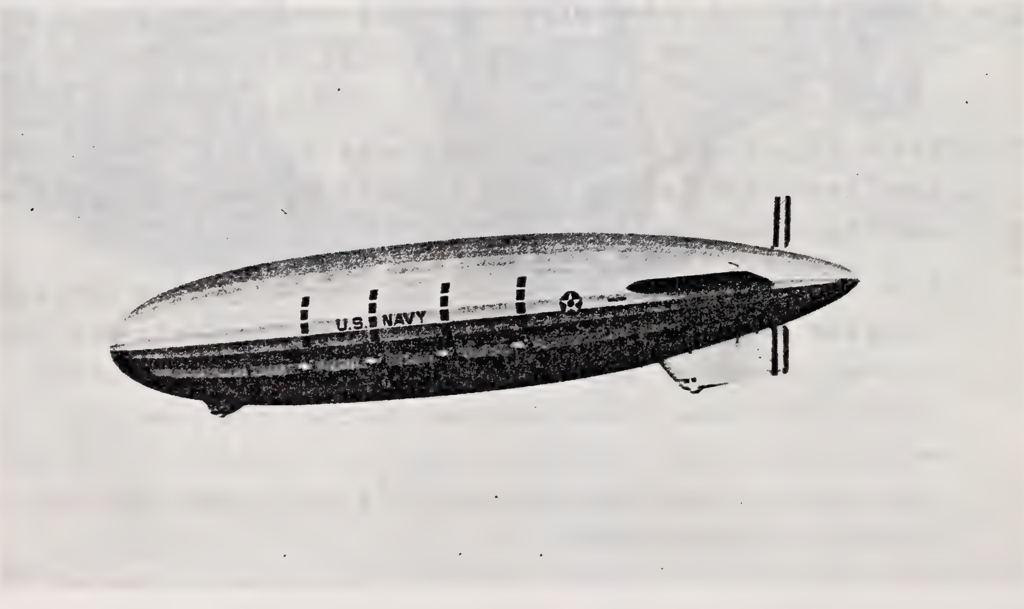


Figure 4 - Rigid Airship (MACON) In Flight

2.2.2.1 Non-Rigid MCA Configurations Considered During Study

Figure 5 illustrates the ZPG-X class of modern non-rigid airships that Goodyear has had under investigation in recent years. These investigations are both U.S. (Government) and corporately funded.

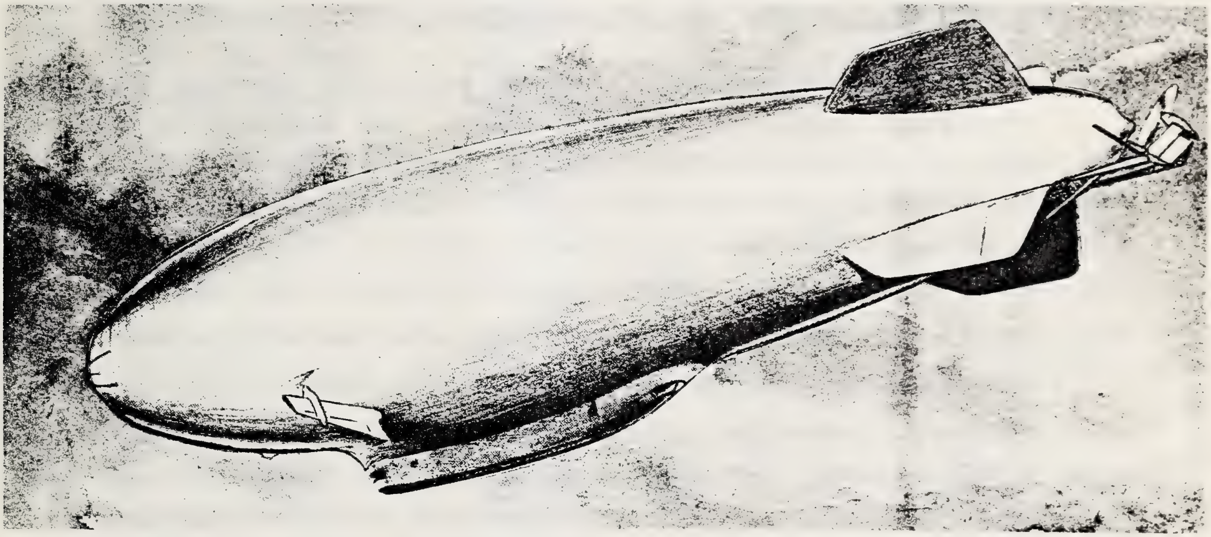


Figure 5 - Modern Conventional Non-Rigid Airship (ZPG-X Configuration)

The ZPG-X is a near-term low-risk concept which is based on a derivative of the successful non-rigid airships developed and used operationally by the U.S. Navy up through the early 1960's. The design provides significant improvements over previous airships in low speed flight control, hover capability, and ground handling during take-off and landing. The vehicle will vertical take-off and land and is hover-capable in heavy or light conditions. These improvements are primarily due to the propulsion system of the ZPG-X which consists of two major elements; the main engines and the stern engine. The main (forward) engines are mounted on a tilt wing with a rotational capability of 90°. The wing is an aluminum alloy stressed skin structure with internal fuel tanks, which provides the structural support for the two main engines and the engine cross-shafting.

The stern propulsion system, which uses a twin turbine engine installation, is mounted on an inverted "VEE" tail which provides rotation capability from 0° to 90°. The "VEE" tail also supports the deflectable ruddevator which provides control capability in both hover and low speed cruise via ruddevator deflection in the propeller slipstream.

As noted in Table V, two sizes of non-rigid airships have been considered during the present study. The ZPG-X-3W is a derivative of the ZPG-3W (See Figure 3) built by Goodyear in the late 1950's. The ZPG-3W, which is the largest non-rigid airship ever built, was operated by the U. S. Navy in an airborne early warning role. The envelope volume for the configuration is the same as the ZPG-3W and hence the designation ZPG-X-3W.

The ZPG-X-3W envelope is essentially the same as the ZPG-3W envelope, empennage, and car configuration with the following modifications. The stern region of the original envelope has been modified to accommodate the stern propulsor structural attachment and tilt mechanism. The car has been lengthened to provide the structural attachment and thrust balance requirements for the forward propulsors. The overall vehicle length is 123 m (405 feet) and the overall width is 26 m (85.7 feet), the height sitting on the ground is 31.85 m (104.5 feet). The total air displacement or hull volume in the unstretched condition is 42,200 cubic metres (1.49 million cubic feet). The fineness ratio of the ellipsoidal hull is 4.55 and the buoyancy ratio is 0.86 at maximum vertical take-off gross weight. In the nominal 1524 m (5000-foot) design pressure height condition the helium volume is 37,000 cubic metres (1.3 million cubic feet), the ballonet capacity is sufficient for a 3,048 m (10,000-foot) pressure height.

The main power plants are 1500 SHP Lycoming T53 (LTC1K-4C) turboprop engines, each driving a Curtiss Wright reduction gear box and three-bladed lightweight (contra-rotating) propellers. The main propulsors are full cross-shafted. The main engines and cross-shafting configuration are based on the Canadair CL-84 tilt wing V/STOL aircraft, which was successfully built and flight tested, with its initial flight in 1970.

The stern propulsor is a twin-turbine installation which uses two Allison Model 250-C20B, 420 HP turboshaft engines. Both turbines feed a reduction gear box (Input RPM = 6000, Output RPM = 708) which drives a 3-bladed constant-speed propeller.

Figure 6 illustrates the general arrangement of the ZPG-X-3W and a top level weight statement is provided in Appendix C.

The second modern non-rigid airship considered during the present study was the ZPG-X-5K which is a derivative of ZPG-5K airship built by Goodyear for the U. S. Navy. The ZPG-5K was employed during World War II by the U. S. Navy in primarily a submarine patrol capacity. The ZPG-X-5K, like the ZPG-X-3W, utilizes two main (forward) engines and a stern propulsion system to achieve the desired improvements in the low speed, hover, and ground handling qualities of previous airships.

Figure 7 illustrates the general arrangement of the ZPG-X-5K and Table VI summarizes the nominal characteristics of the configuration.

2.2.3 Heavy Lift Airships (HLA)

2.2.3.1 General

The Heavy Lift Airship (HLA) considered herein (see Figure 1) is a configuration which combines buoyant lift derived from a conventional helium-filled airship hull with propulsive lift derived from conventional helicopter-type rotors.

Figure 6 - General Arrangement of Hover Capable ZPG-X-3W
(Goodyear Drawing No. 78-315)

Figure 7 - ZPG-X-5K General Arrangement Drawing
(Goodyear Drawing No. 78-314)

TABLE VI. NOMINAL CHARACTERISTICS OF ZPG-X-5K

	Kilograms (kg)
Normal Take-off Gross Weight	18,185
Static Lift	14,642
Empty Weight	10,505
Avionics	544
Useful Load *	7,135

* At 1524 m altitude, standard day

The HLA represents a combination of proven technologies and possesses performance and operational characteristics which suggest it is ideally suited for a wide range of Canadian heavy-lift requirements.

The buoyant lift essentially offsets the empty weight of the vehicle; thus the rotor thrust is available for lifting the useful load and to maneuver and control the vehicle. The ability to offset the entire empty weight of the vehicle with buoyancy permits a quantum increase in current and projected helicopter lifting capabilities plus a substantial reduction in current vertical lift costs.

The flight crew is accommodated in a central control car much like conventional airships. The HLA is controlled by a command pilot using proven Fly-By-Wire (FBW) techniques. Automatic control in the flight and hover modes, with the hover capability enhanced by a Precision Hover Sensor (PHS), would be provided in addition to the manual flight modes. The Automatic Flight

Control System (AFCS), PHS and FBW electronics required for the HLA involve principles, techniques, and hardware developed and demonstrated during the U. S. Army Heavy Lift Helicopter Program.

The concept also eliminates the necessity of interchanging ballast and payload which significantly simplifies operation of this device in remote, unprepared areas. In addition, the concept significantly improves the low speed control and hovering qualities of prior airships (due to the larger rotor forces that are available for control) while also leading to improved ground handling characteristics. The classical helicopter problems of high fuel consumption and airframe weight are implicitly minimized in the concept. Further, significantly improved cost, maintainability and reliability characteristics appear to be available by developing dedicated propulsion systems (rotor/turbine/transmission modules) for use on the operational HLA's. The HLA concept is relatively immune to scale effects and prior analyses (References 1 and 21) have shown that payloads up to several hundred kilograms can be transported several hundred kilometres. By providing the rotor system with a capability of generating both positive and negative thrust, larger vehicle lifting capabilities can be developed for any given number and size of rotors. There are certain advantages and disadvantages that are introduced with such a configuration. These items are discussed in additional detail in Appendix B.

Goodyear has conducted an extensive technical evaluation of this configuration in recent years. Major areas of investigation have included: (1) a point design analysis (aerodynamics, flight dynamics, controls, structures, and weights); (2) acquisition and total operating costs analysis; (3) an operational analysis; and (4) a technology assessment analysis.

REF: EO1 380

A corporately funded powered wind tunnel model of the HLA was evaluated in the NASA Ames 7 x 10-foot wind tunnel facility (See Figure 8). The results of these tests indicate the aerodynamic feasibility of combining large rotors in close proximity to a large hull. These tests have also shown that the crosswind station-keeping capability of the vehicle can be improved by modifications, such as changing rotor locations, to the current HLA configuration.

As an additional area of corporate support, a Six Degree-of-Freedom (6-DOF) hybrid computer flight dynamics simulation was developed to assess the flight dynamics and precision

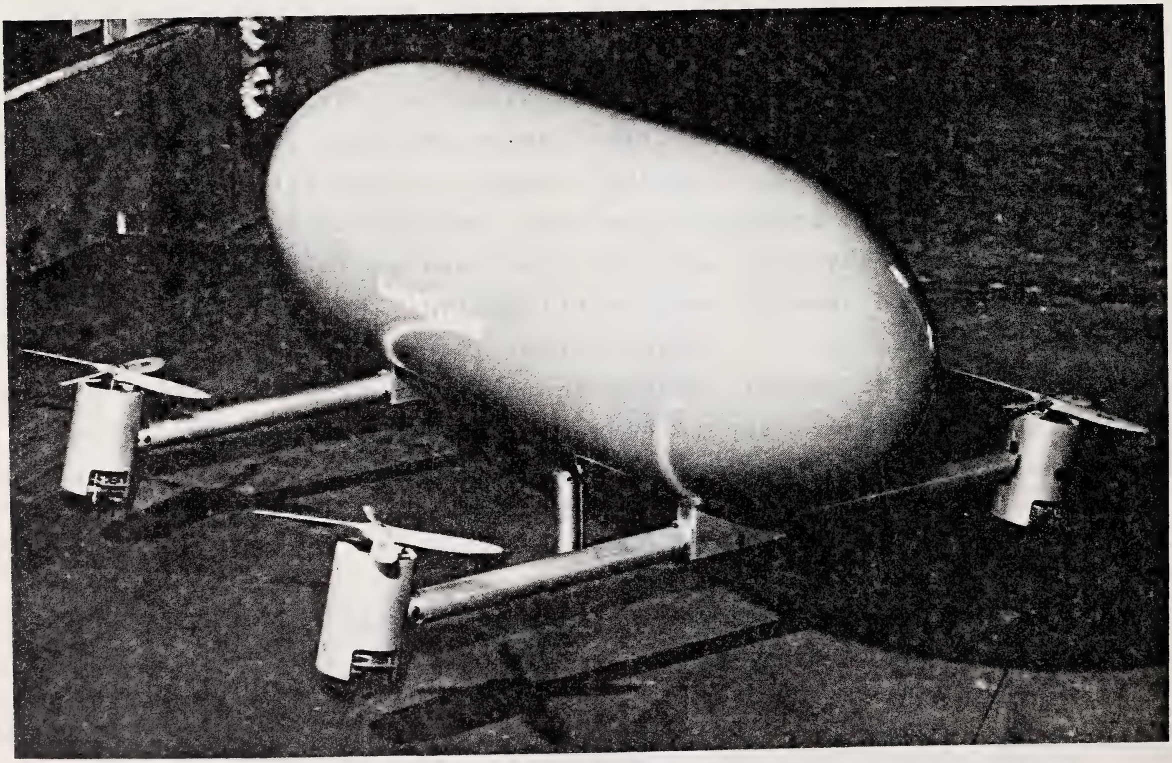


Figure 8. Powered Model in NASA 7 x 10-Foot Wind Tunnel Facility in Presence of Ground Plane

hover mode accuracy of the HLA in response to atmospheric turbulence and to assist in the synthesis of the fly-by-wire control laws and autopilot system. Based upon the wind tunnel and flight dynamics simulation efforts it appears that the HLA has sufficient controllability to perform the military and civil missions for which it is being considered over an acceptable range of atmospheric conditions.

Various structural arrangements and material trade studies were performed in order to minimize structural weight, while maintaining acceptable acquisition costs. The major structural elements of the configuration are shown in Figure 9.

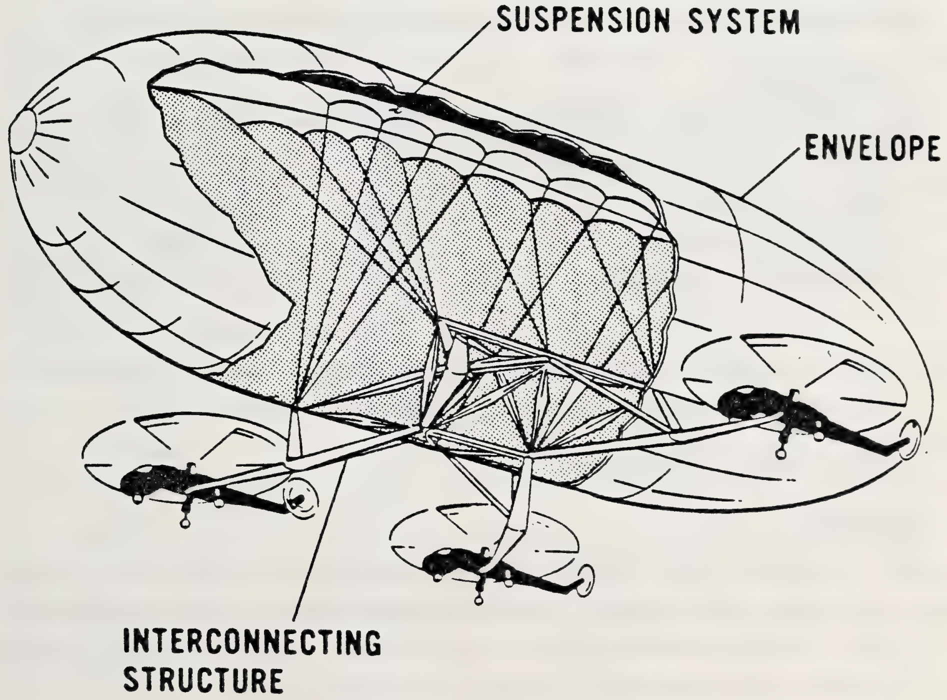


Figure 9. Major Structural Elements of HLA

Economic analysis (See Section 4.3) indicates the Total Operating Costs (TOC) of the HLA on a payload kilogram-kilometre basis to be substantially reduced over current large helicopter vertical lift costs basically due to the economic leverage afforded by the buoyant lift.

A technology assessment of the HLA (completed as a part of the Reference 22) indicates that there appears to be no major unresolvable technology problems and thus the concept is basically feasible. However, additional data and analysis capability is needed in several technical areas before an operational HLA can be designed with low risk in a timely manner. As part of prior studies, a technology development program to supply this information has been outlined. This program is discussed in Section 4.6 of this report.

2.2.3.2 HLA Sizes

As indicated in Table V, the Canadian heavy-lift requirements extend over quite a range of payload weights. As a result a range of HLA useful loads 45,372-142,468 kg (50-157 tons) were considered during this study. Appendix B summarizes the parametric analysis performed, as a part of this study to: (1) size the vehicles; (2) to define the vehicle empty weights; (3) to define the vehicle acquisition costs; and (4) to define the vehicle total operating costs.

3.0 OPERATIONAL ANALYSIS

3.1 General

An operational analysis was completed primarily to define the permanent and remote basing requirements for an airship transport service operating in the study area and the compatibility between the airship configurations and the Canadian environment.

3.2 Permanent and Remote Basing Requirements

In order to generate representative economic case study information (see Section 4.4) it was necessary to select permanent base locations for an airship operating company. As indicated in Figure 10, a base site has been selected in Southern Alberta and one at Hay River, NWT. These are, at most, representative locations emerging from the mission definition and economic case study efforts to date and are subject to considerable further study. Based on further study, there may well be good rationale developed for moving the base in Southern Alberta nearer to the major population centers of Calgary and Edmonton. There may be equally good rationale for moving the base at Hay River into Northern Alberta.

The principal rationale for selecting two permanent bases relates primarily to a desire to maintain reasonable ferry distances for the airships. As indicated in Figure 10, a ferry distance of 925 km (500 nm) from each of the permanent bases encompasses a considerable market area of interest. The economic case studies of Section 4.4 are based on the concept that any point within the two circular areas is a point of origin.

To simplify the case study calculations a fixed round trip ferry distance of 1,851 km (1,000 nm) was considered in all cases. This is not to suggest that it will be 1,851 km (1,000 nm) between points of origin (or job sites) nor is it necessary to return to the permanent base after each job. However, some assumption was essential in this respect and it is believed that the assumption made, on the average, is conservative.

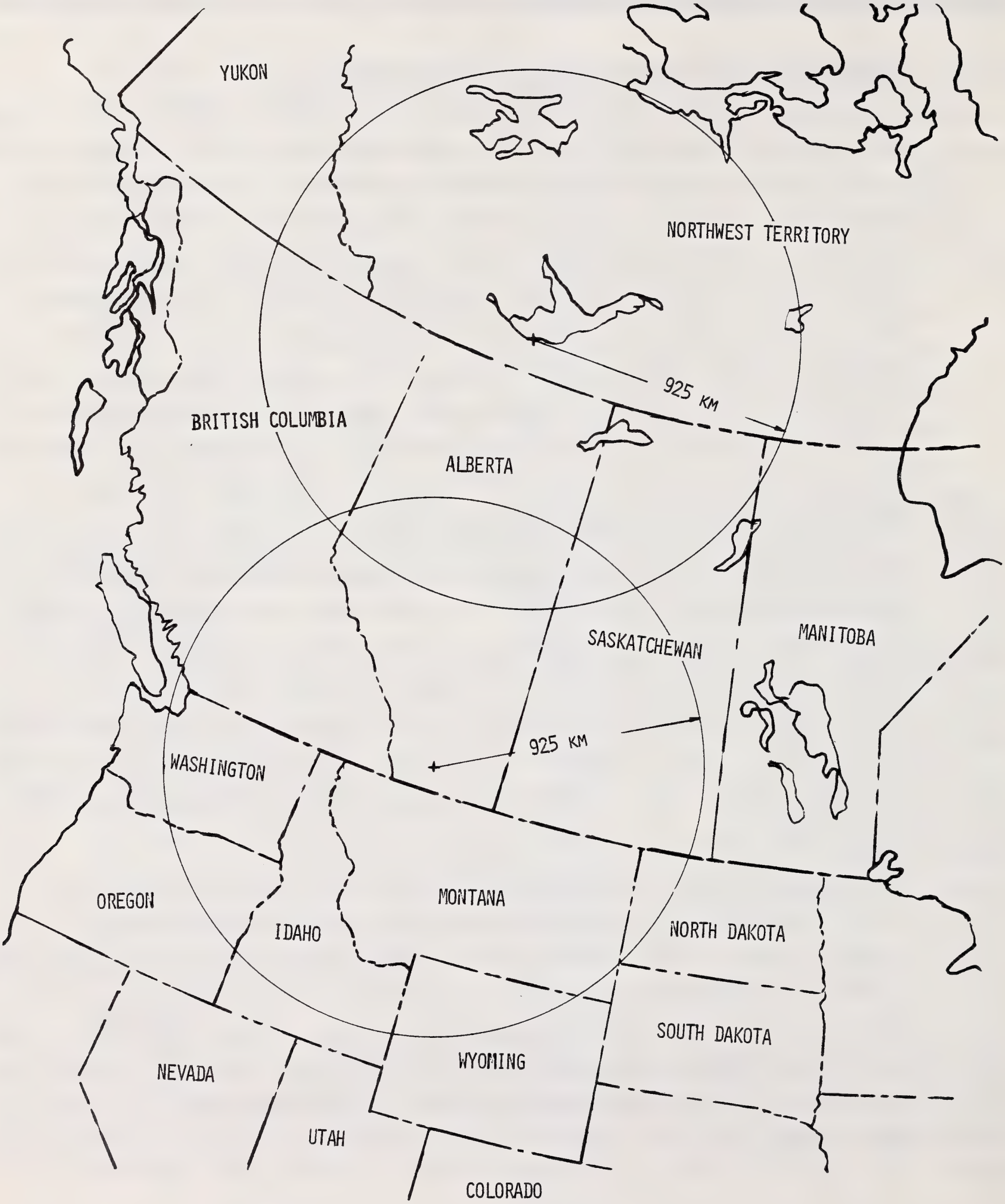


Figure 10 - Permanent Basing Locations

3.2.1 Permanent Basing Requirements

Figure 11 illustrates a typical permanent base installation; consisting of hangar, paved mooring circle, mobile mooring mast, and ground handling tractors. It should be noted that the TOC analysis of Section 4.2 includes the costs of all permanent base items, except the hangar. It appears that governmental support is available for such facilities as an encouragement to private enterprise.

The airships, while at the permanent base, will typically be moored outside the hangar. Only for major maintenance of the envelope will it be necessary to dock (place airship in hangar) the airship. There may be other occasions when the airship would be docked to facilitate other maintenance.

3.2.2 Remote Basing Requirements

When remote basing is required, proven expeditionary (or stick) masts will be used as shown in Figure 12. A cleared, non-paved area will be required. The expeditionary mast can be carried in most cases by the airship and can be erected by a crew of two or three within a few hours. A stick mast, capable of handling the largest non-rigid ships built to date is shown in Figure 13. Operation from bases without hangar facilities were routinely accomplished by the U. S. Navy during World War II as discussed in Section 3.3 below.

It should be realized that operation into remote areas does not necessitate mooring of the airship. In fact, viable concepts are available for remaining airborne while at remote sites thus avoiding any necessity of remote basing.

3.3 Environmental Factors

Historically airships have demonstrated substantial all-weather capability. During the mid-1950's the U. S. Navy conducted

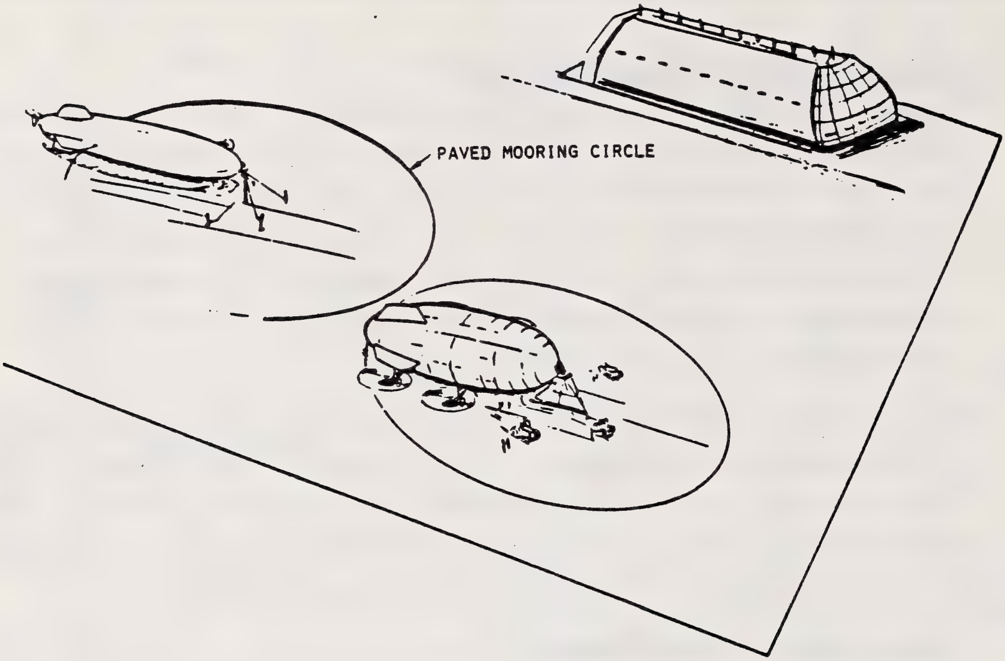


Figure 11 - Permanent Basing Requirements

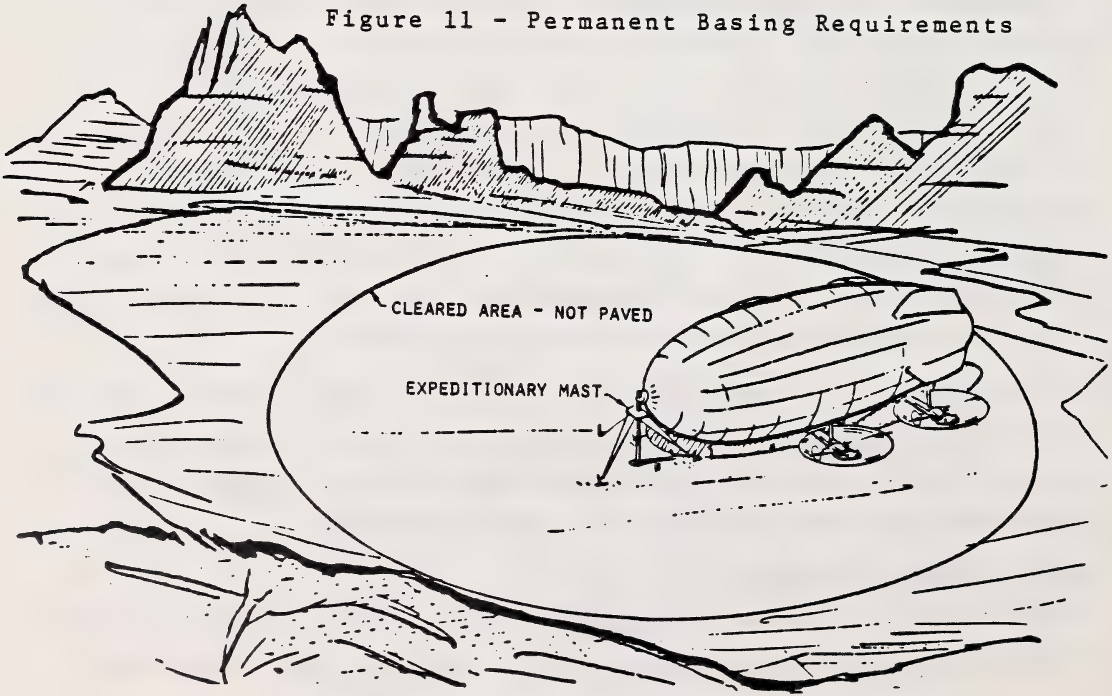
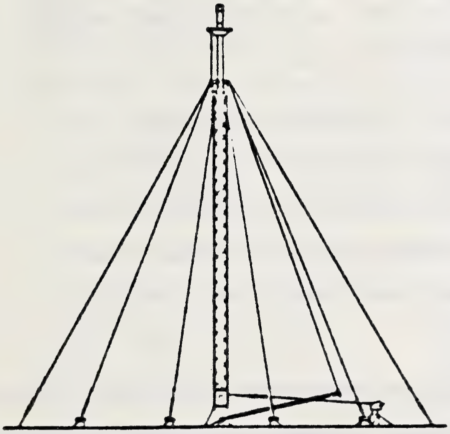


Figure 12 - Remote Mooring Requirements



Application	ZPG-2/-2W-3W Airships
Air transportable	By cargo aircraft
Winch load	Up to 144 km/h
Total weight	56,917 kg
Height	
(Total)	21.78 m
(Telescoped and less removable section)	17.50 m
(Telescoping head)	2.21 m
Head elevation	By manual winch
Mast elevation	By gin pole from horizontal position
Mast cup control	Manual
Gear Box	
Capacity	Rated 11,794 kg
Reduction ratio	1000 to 1
Ground anchor diameter	21.39 m
Construction	
(Type)	0.75 m square frame
(Material)	Aluminum and steel

Figure 13. Type V_S Stick Mast Specifications

flight exercises off the northeast coast of the U. S. in the worst winter weather experienced in that area in many years. Icing, fog, sleet, snow, rain, and gale winds were encountered. A station was manned continuously for 240 hours using five airships. Eleven flights were made. The "icing" ship accounted for five of the flights and on one flight spent 30 hours in icing conditions. Even though field conditions at South Weymouth were rigorous, the operations were conducted off a mobile mast and the airship was hangared only once for a regular maintenance check.

The conclusions of the official U. S. Navy report were:

> "Airship ground handling evolutions can be accomplished in virtually all weather conditions.
>
> "Routine ground maintenance can be accomplished under extremely adverse weather conditions.
>
> "Rime ice accretion at normal airship operating altitudes is not considered a deterrent to proper stationkeeping for protracted periods of time.
>
> "Maintaining a continuous barrier station over the Atlantic Ocean appears to be feasible under all weather conditions."

Wind is the most important weather element in airship operations. However, while high winds in themselves are no threat to the structural safety of a properly designed airship, historically the limited speed of the airship necessitated that high head winds be avoided by flying the pressure patterns. This technique has been demonstrated in countless instances dating back to Germany's World War I operations.

Ground operations can be delayed, particularly where the winds are turbulent. The airship's ability to remain aloft with minimal fuel consumption and thereby briefly delaying a landing until the unfavorable period passes was a demonstrated operational technique. Of course, this is a common practice with heavier-than-air aircraft. Where the fuel supply was low, the Navy relied on in-flight pickup of fuel in containers while the airship was hovering or flying at low ground speed.

Airships have been masted out in winds up to 167 km/h (90 knots) and can be docked and undocked in down hangar winds up to 74 km/h (40 knots). As the wind direction approaches 90 deg to the axis of the hangar, the maximum velocity for docking operations approaches 37 km/h (20 knots).

Thunderstorms are typically avoided; however, experienced pilots have shown during hundreds of flights in thunderstorms that properly designed airships can safely fly in this environment. Modern weather forecasting, communications, and constant weather updates along with onboard radar would ensure an airship's being able to avoid a thunderstorm. Goodyear advertising airships are today configured with onboard radar for such purposes.

Perhaps the most troublesome situation for a moored airship is when a heavy, wet snow of several inches accumulates on the hull and fin topsides. In several instances, the Navy has flushed the snow off with a fire hose. Some promising experiments have been conducted in which the envelope helium was heated to melt the topside snow, but the Navy did not think it necessary to make this operational. As discussed in Section 4.6, additional development is considered necessary in this area.

Wet snow usually occurs near the ground and can be avoided in flight by a moderate increase in altitude.

Lightning has never caused concern with a helium-inflated airship. Although all aircraft attempt to avoid lightning areas because of the turbulence that usually exists, there has been evidence of strikes on airship cars, fins, and topside radomes but none that caused detectable damage to an envelope of a non-rigid. There have been reports of small holes in the outer coverings of rigid airships where charges hit the metal structure beneath, but the structure was not damaged.

The most convincing demonstration of the all-weather capability of airships took place during U. S. Navy operations in World War II when airships patrolled nearly 7,772,000 km^3 (3,000,000 square miles) over the Atlantic, Pacific and Mediterranean. Only two bases outside the United States had hangar facilities. A significant factor in this performance was the high availability factor. Of the airships assigned to fleet units, 87 percent were on the line at all times; that is, they were in operation or in readiness for operation, which was a high factor for military aircraft during the war.

3.3.1 Impact of Wind on Canadian Airship Applications

From the data presented in Figure 14 it can be seen that the mean wind velocities in Canada are moderate. While the summer months have slightly higher mean wind velocities than the winter months, they are not appreciably different than those indicated in Figure 14 for January. Although not indicated in Figure 14, mean wind conditions are somewhat higher in the spring and fall along the coastal regions. From available data, it is generally concluded, since the cruise speed of the airships considered during this study are in the 148 km/h (80 knot) range, that the mean wind conditions within Canada offer no serious operational drawback in terms of reduced operational utilization or reduced vehicle productivity.

Available data suggests that wind gusts (which are typically of short duration) do not represent a concern from an operational standpoint either during flight or when moored. Prior airship experience indicates there will be infrequent periods when take-off, landing, precision placement and ground handling operations will be momentarily delayed due to gusting conditions. In comparison to prior airships, the modern airship configurations

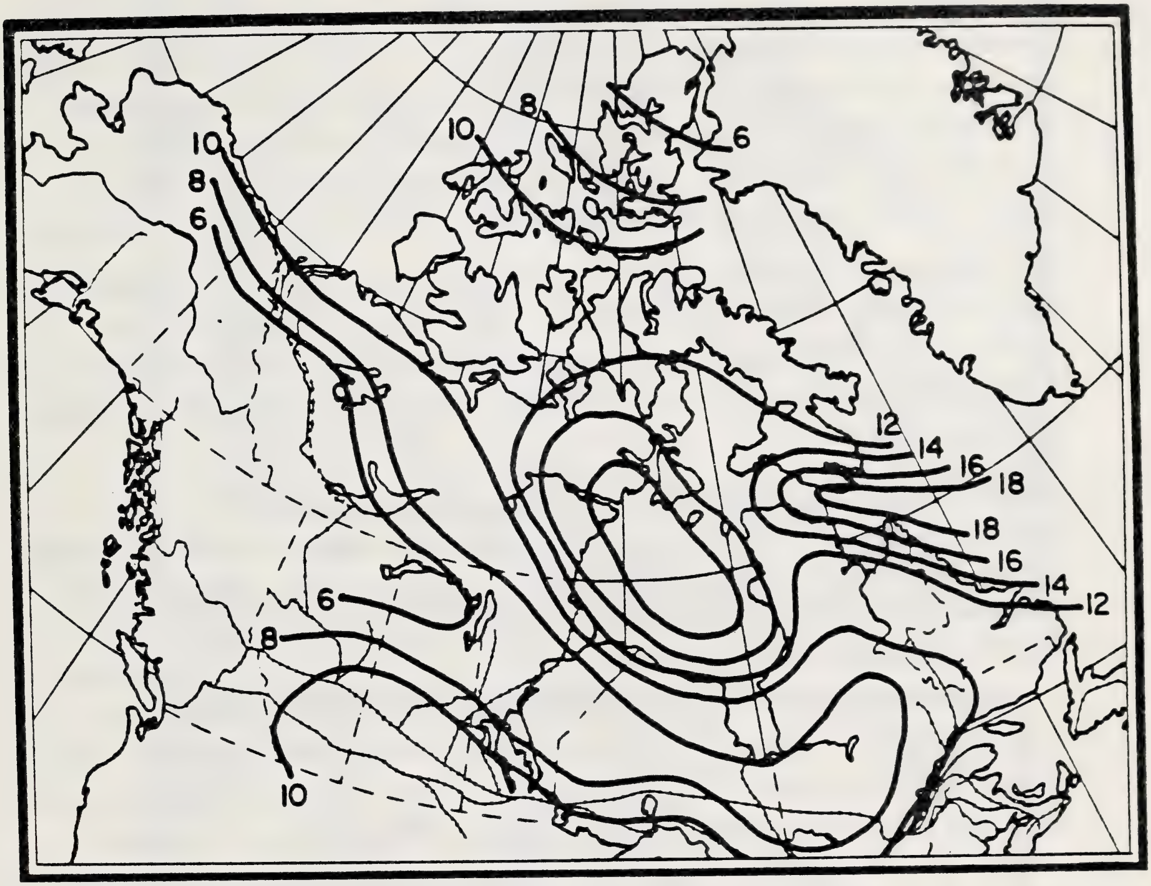


Figure 14. Mean Wind Speed (MPH) . . . January

considered herein will not be as sensitive to wind conditions during flight and ground operations due to the capability of vectoring available propulsive forces to minimize response to wind gusts. The heavy lift airship represents a particularly significant improvement in that area due to the large rotor forces available.

There will also be periods when blowing snow will reduce visibility to the extent that it may become impractical to conduct productive air operations. From an operational standpoint, an airship has a definite advantage over fixed wing aircraft in operating in reduced visibility conditions (fog and blowing snow) due to its ability to remain airborne at zero ground speed and/or land at a very low closing velocity.

Airships and airship mooring equipment are usually designed to withstand wind velocities of 139 km/h (75 knots). As stated previously, airships have successfully masted out in 166 km/h (90-knot) winds which encompass the recorded extremes within Canada.

3.3.2 Impact of Cold on Canadian Airship Applications

There is ample evidence relative to existing fixed and rotary wing air operations illustrating the point that appropriate cold weather procedures are a must in the Canadian North. Cold weather procedures and techniques in use for fixed and rotary wing aircraft will, of course, be essential to the successful introduction of an airship operation in that area. Docking the airship for maintenance during severe winter cold may be desirable but does not appear essential. Portable shelters, however, would be a requirement to protect workers from the cold and wind chill effects.

Figure 15 indicates the type of mean low temperatures that can be expected during the coldest part of the winter. Figure 16 indicates the lowest temperature extremes recorded in the study area. Figure 17 indicates the frequency during the winter season when the daily minimum temperature dropped to or below -37° C (-30°F).

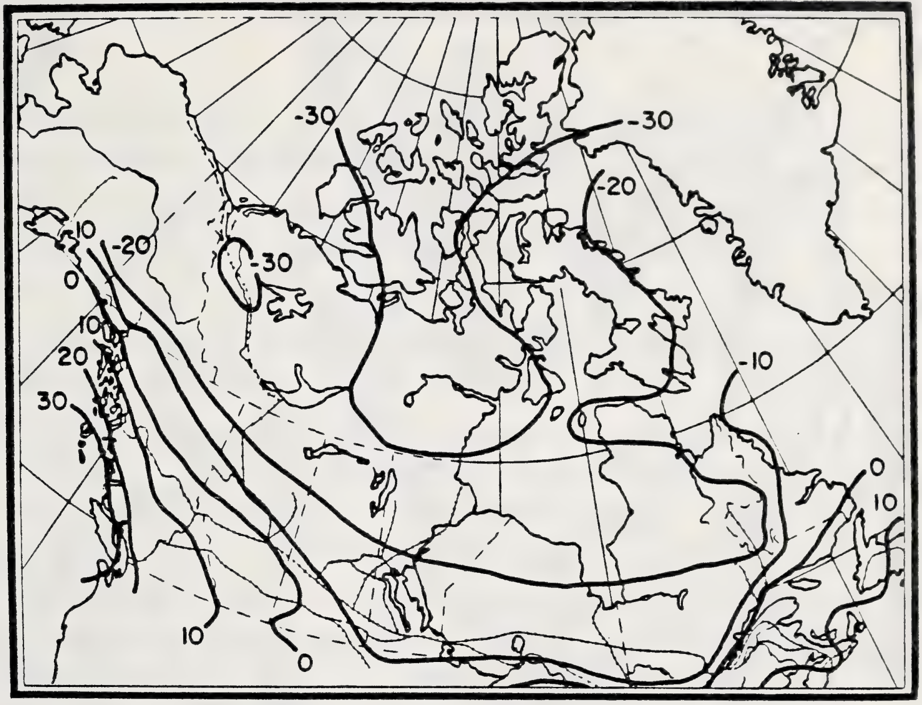


Figure 15 - Mean January Daily Minimum Temperature (°F)

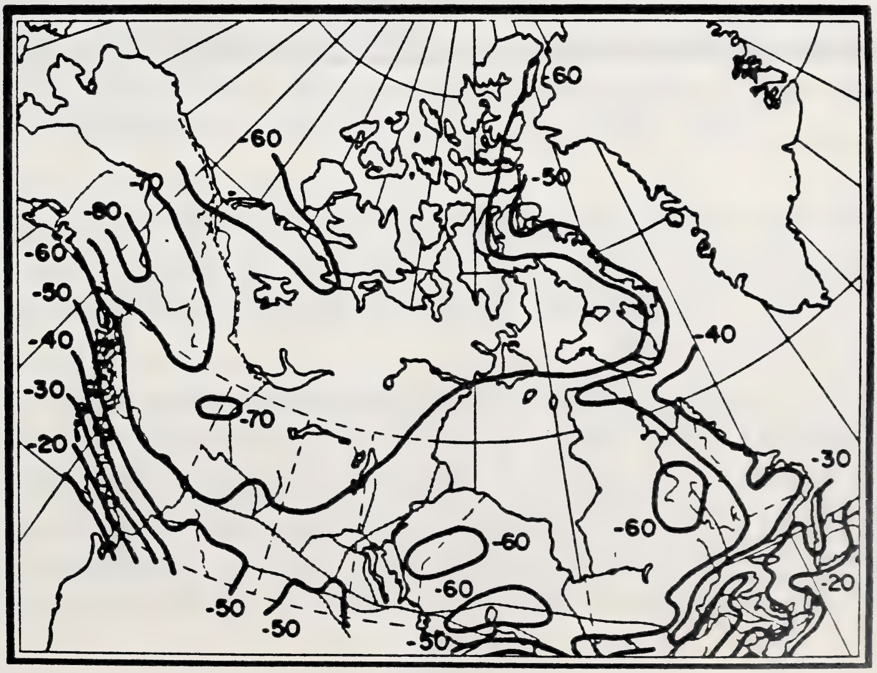


Figure 16 - Extreme Lowest Recorded Temperature (°F)

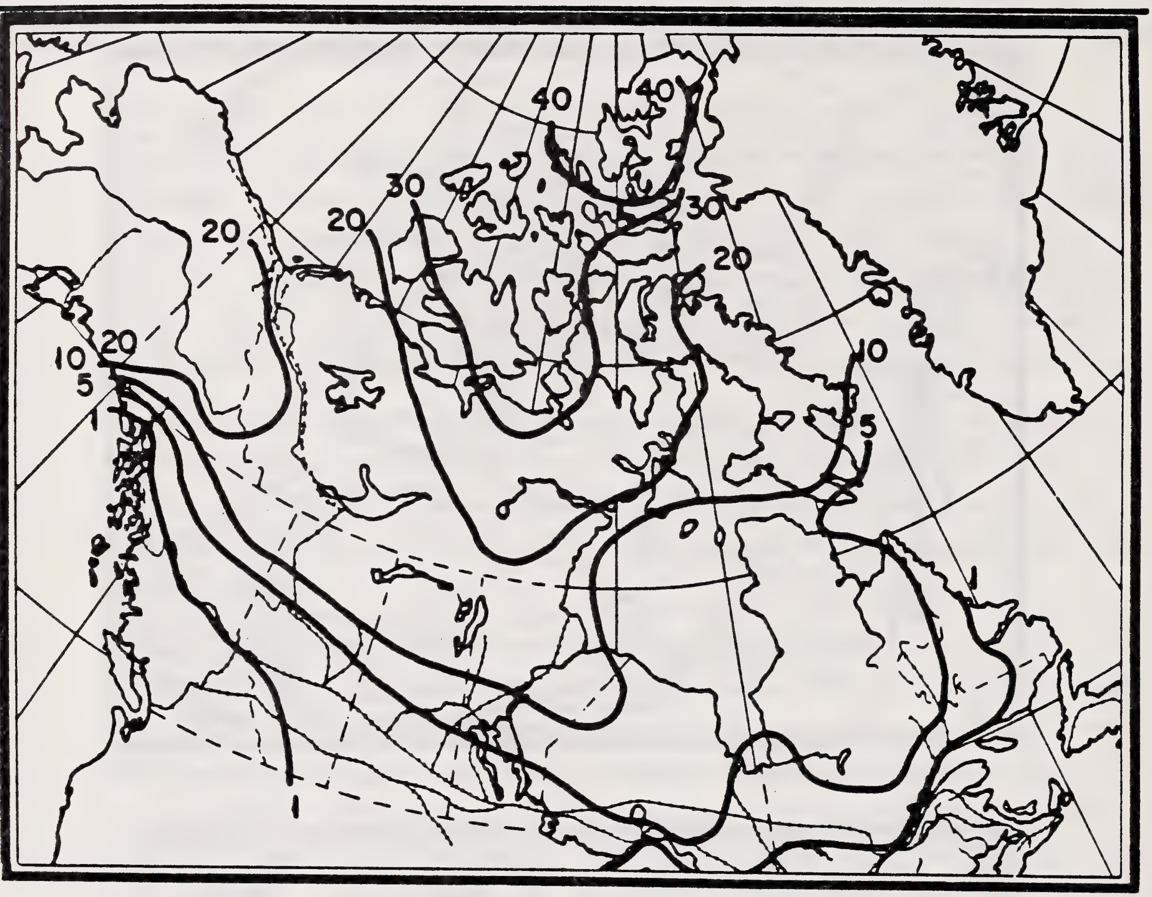


Figure 17 - Frequency (%) Of Daily Minimum Temperature At Or Below -30° F During The Whole Winter Season

Available data suggests that most non-scheduled air operations are generally halted below -40°C (-40°F) because of increasing costs and the stoppage of activities that these air services may be supporting.

Fabric (coated cloth) is the only significant airship component not generally present in fixed and rotary wing aircraft. There are presently better low temperature fabrics available than are currently used in Goodyear's existing airships. Of course, these airships are not operated in arctic conditions and therefore do not require fabrics capable of arctic operation. The available fabrics with improved low temperature characteristics are comprised of the same cloth substrate (polyester) as current fabrics and are also coated with the same generic elastomer (neoprene). The compounding of the elastomer is altered somewhat, however, to improve its low temperature flexibility, etc.

On the basis of available data, it would appear that an airship capable of operation down to -40°C (-40°F) would not represent any serious operational limitations (in terms of utilization) relative to current rotary and fixed wing operations. An ability to be moored out in -62°C (-80°F) conditions would encompass all cold extremes on record in Canada. Tailoring the fabric properties to exhibit suitable characteristics at the above temperatures is not considered a significant developmental effort.

3.3.3 Impact of Snow on Canadian Airship Operations

Figure 18 gives a representative picture of the snowfall distribution across Canada. The arctic coastal regions are classified as arid and the Mackenzie Valley as semi-arid. Thus snowfall is light in these areas and, of course, dry due to the extreme cold.

In general, then, it can be expected that snowfall in the cold dry portions of Canada will not represent any problem to airship operations during flight or when moored.

The only significant area of Canada where snowfall would represent any operational concern is in Southeastern Canada where the snow is heavy and at times is wet. As noted previously, wet snow accumulation on moored airships has historically been a problem. Methods were successfully implemented by the U. S. Navy to remove the snow but the methods are not considered

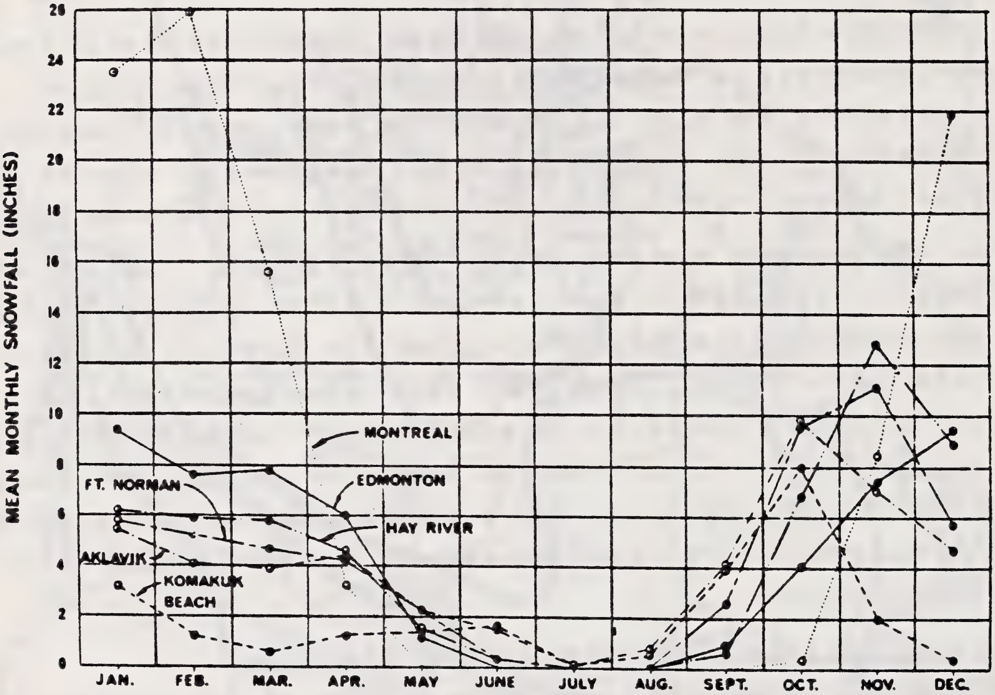


Figure 18 - Climatic Comparison -- Snowfall

significantly desirable to be compatible with a commercial operation. Substantial experimentation was initiated by the Navy in the 1950's to improve snow removal techniques. It can be anticipated that additional developmental efforts in this area can lead to substantial improvements in historical snow removal techniques.

3.3.4 Turbulence and Thunderstorm Operation

It has been typical in past airship operations to avoid thunderstorms; however, experienced pilots have shown that properly designed airships can safely fly in this environment.

In general, modern airships will also be operated in such a manner as to avoid heavy thunderstorms as do all aircraft today. Current avionics and communications equipment onboard coupled with current long range weather forecasting capabilities will permit significant improvement in the successful procedures developed in the past for avoiding storm areas.

4.0 ECONOMIC ANALYSIS

4.1 General

An economic analysis was completed to ascertain the economic viability of airships performing the applications identified in the mission definition phase of the study. These applications were summarized previously in Table IV. The economic analysis performed during the study has two principal elements: (1) the development of a rental service price for the various airship configurations; and (2) economic case studies for the applications of Table III in order to show the cost benefit that the airship provides.

Figure 19 indicates the general approach used in estimating the rental service price for each airship configuration.

4.2 Total Operating Cost Analysis

The Total Operating Cost (TOC) is comprised of two major elements: (1) Direct Operating Cost (DOC); and (2) Indirect Operating Cost (IOC). The DOC includes those items related directly to acquiring and operating the vehicle. It does not include the cost of money to acquire the vehicle and associated spares. This cost is included in the factor of Figure 19 which escalates TOC to rental price.

In order to maintain the size of the report to a reasonable level, only the details of the TOC analysis for the HLA are provided

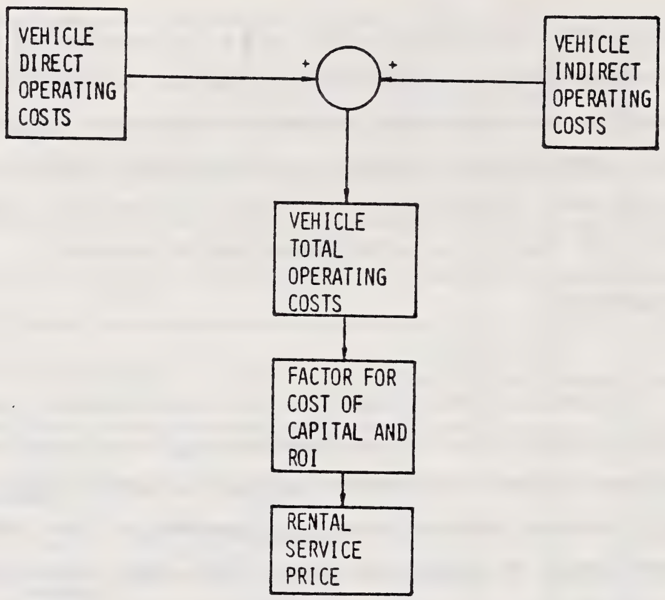

VEHICLE DIRECT OPERATING COSTS
+
+
VEHICLE INDIRECT OPERATING COSTS
VEHICLE TOTAL OPERATING COSTS
FACTOR FOR COST OF CAPITAL AND ROI
RENTAL SERVICE PRICE

Figure 19 - Current Method For Establishing Rental Service Price

herein (See Appendix B). Summary data is provided for the other configurations.

4.2.1 Direct Operating Cost Analysis

The vehicle direct operating cost elements are illustrated in Figure 20. Appendix B provides, for the HLA configuration, the manner in which the elements of Figure 20 have been generated.

The magnitude of the DOC and TOC is strongly a function of the number of vehicles produced and the number of hours a vehicle is used per year. As a result it is often valuable to parametrically define the DOC and TOC as a function of vehicle quantity and vehicle utilization. An example of this is presented for the HLA configuration in Appendix B.

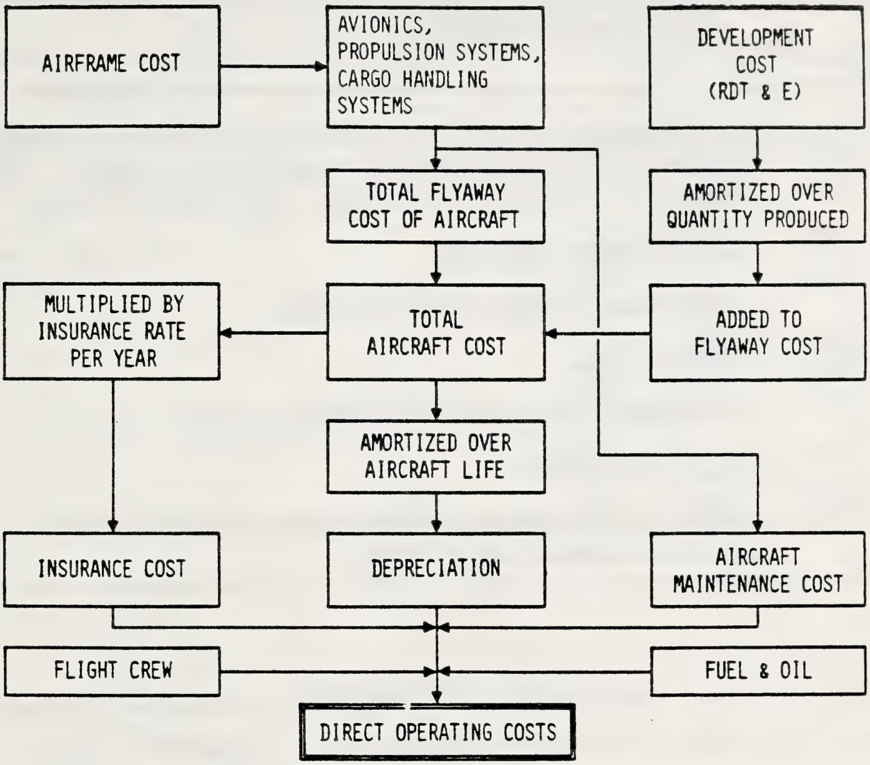

AIRFRAME COST
AVIONICS, PROPULSION SYSTEMS, CARGO HANDLING SYSTEMS
DEVELOPMENT COST (RDT & E)
TOTAL FLYAWAY COST OF AIRCRAFT
AMORTIZED OVER QUANTITY PRODUCED
MULTIPLIED BY INSURANCE RATE PER YEAR
TOTAL AIRCRAFT COST
ADDED TO FLYAWAY COST
AMORTIZED OVER AIRCRAFT LIFE
INSURANCE COST
DEPRECIATION
AIRCRAFT MAINTENANCE COST
FLIGHT CREW
FUEL & OIL
DIRECT OPERATING COSTS

Figure 20 - Direct Operating Cost Model

4.2.2 Indirect Operating Cost Analysis

The indirect operating costs are non-vehicle related expenses that would be incurred in the operation of a commercial airship rental service. Table VII summarizes the indirect elements associated with such a service.

It should be noted that the IOC analysis does not include the cost of a hangar facility. It appears that Governmental subsidy may be available in this area in order to encourage private enterprise to establish a transportation service that contributes to the economic growth of the study area. It is also

TABLE VII - INDIRECT OPERATING COST ELEMENTS FOR A RENTAL SERVICE OPERATION

ITEM NO.	ITEM
1	OPERATIONS/MAINTENANCE BUILDINGS, OPERATIONS AND MAINTENANCE EQUIPMENT, OPERATIONS AND MAINTENANCE SUPPORT VEHICLE, OFFICE EQUIPMENT, SHOP AND TEST EQUIPMENT, FUEL AND OIL STORAGE FACILITIES
2	GROUND SUPPORT EQUIPMENT
3	GROUND HANDLING AND MOORING EQUIPMENT
4	MOORING CIRCLE
5	MAINTENANCE AND MAINTENANCE BURDEN ON ITEMS 1 - 4
6	UTILITIES EXPENSES
7	OPERATIONS MANAGEMENT AND ADMINISTRATIVE SUPPORT MANAGER, ASSISTANT MANAGER AND SECRETARY

possible that certain of the indirect elements of Table VII may fall under a similar situation of subsidy.

4.2.3 Results of Total Operating Analysis

4.2.3.1 Heavy Lift Airship (HLA)

Table VIII and Figure 21 summarize the results of the TOC analysis performed as a part of this study for the HLA. These data have been extracted from Appendix B to this report for the convenience of the reader. Figure 21 simply displays graphically the data of Table VIII for a 90700 kg (100-ton) useful load vehicle.

4.2.3.2 Modern Conventional Rigid Airship

Figure 22 displays typical total operating cost/available data as a function of rigid airship size. In structuring the TOC,

TABLE VIII. SUMMARY OF BASELINE TOTAL OPERATING COSTS FOR NON-RIGID HLA'S (BASELINE CONFIGURATION)

Total Operating Costs ($/hr)					
Operating Mode	Useful Load (kg)	Quantity	Utilization (Hours/Annum)		
			1000	2000	3000
Lift Mode (Cruise, Max GW, 148 km/h)	45350	1	7944	4604	3825
		5	4144	2689	2219
		25	3024	2147	1846
	90700	1	11230	6807	5329
		5	6850	4617	3867
		25	5330	3834	3360
	142427	1	14995	9326	7423
		5	9900	6782	5727
		25	7955	5806	5077

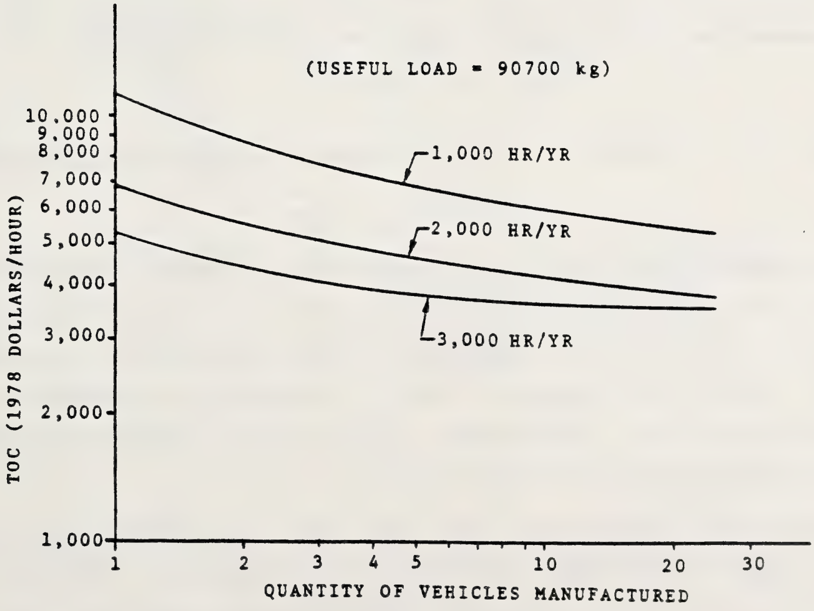
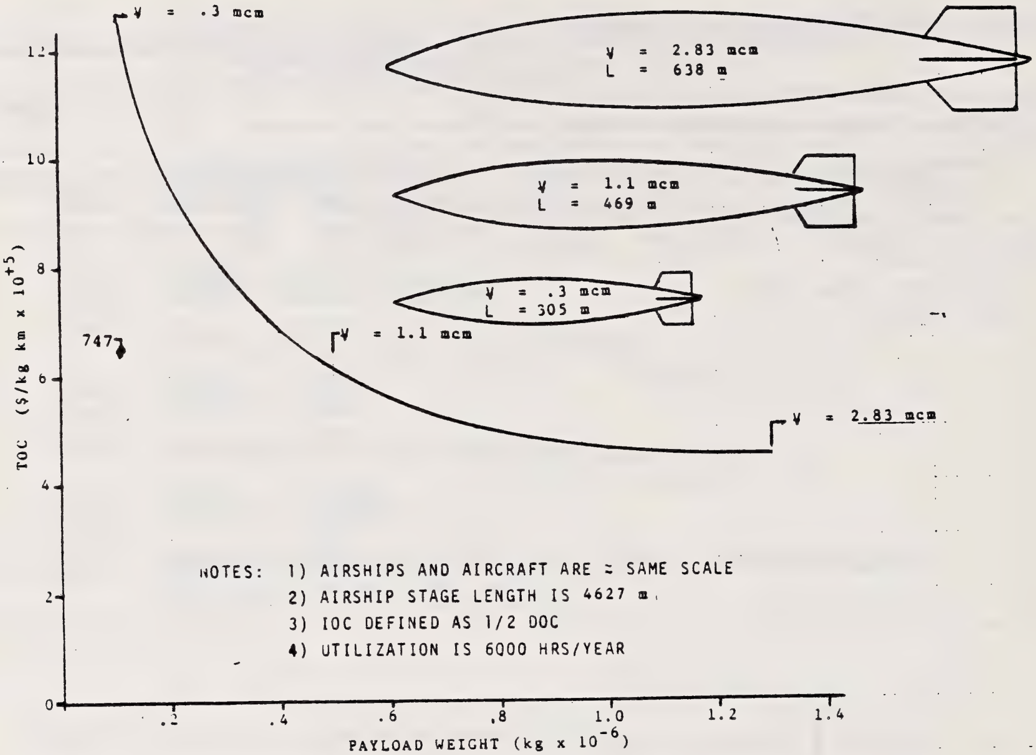


Figure 21. Total Operating Cost (TOC) Versus Quantity of Vehicles and Utilization



NOTES: 1) AIRSHIPS AND AIRCRAFT ARE ≈ SAME SCALE
2) AIRSHIP STAGE LENGTH IS 4627 m
3) IOC DEFINED AS 1/2 DOC
4) UTILIZATION IS 6000 HRS/YEAR

Figure 22 - TOC/HR Vs Payload Weight For Rigid Airships

the assumption has been made that the IOC will typically be 50% of the DOC. For comparative purposes the TOC of the Boeing 747 aircraft has been included based upon the same IOC/DOC ratio. Of course, the 747 requires a runway and the airship does not. This point is discussed further in the case study analysis of Section 4.4.

As previously discussed, only one size of airship has been considered in the case studies of Section 4.4. The size considered in Section 4.4 is the configuration having a hull volume of .3 x 10^6 m^3 (11 x 10^6 cu ft). It will also be apparent to the reader in reviewing the case studies that the data of Figure 22 is adjusted from the stage length of 4,627 km (2500 nm) to the one of interest.

Utilization considered for the rigid airships are considerably higher than for the HLA basically because the stage length for the rigid airship is much longer than for the HLA. Utilizations as high as 6000 hours/year are considered attainable for rigid airships in certain applications. The effect of annual utilization upon TOC is shown in Figure 23.

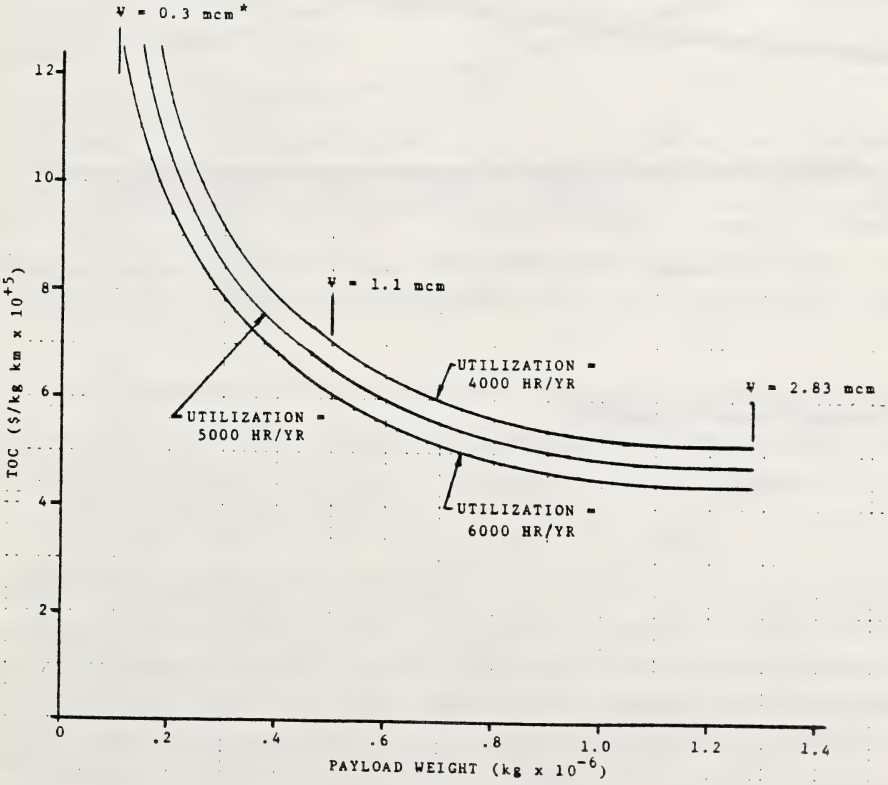


Figure 23 - Effect Of Utilization On Rigid Airship TOC

4.2.3.3 Modern Conventional Non-Rigid Airship

Figure 24 provides typical TOC versus stage length data for the two non-rigid configurations considered in the case study analyses. Again the IOC is taken as 50% of the DOC.

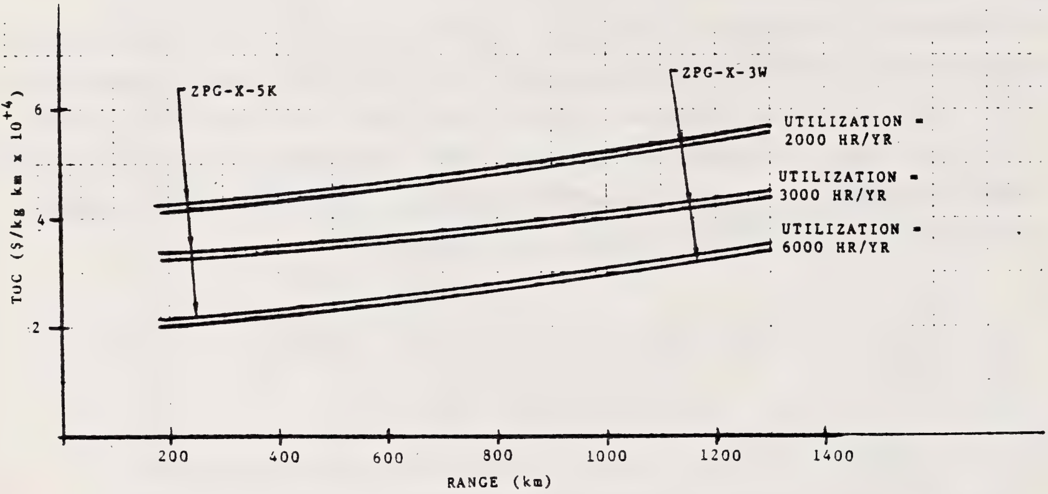


Figure 24 - TOC Vs Range For ZPG-X-5K And ZPG-X-3W As A Function Of Annual Utilization

4.3 Rental Price Comparisons

Figure 25 provides a comparison, on a rental or tariff basis (cost to shipper) for various aircraft operating in the study area and the airship configurations considered herein.

The airship rental price (or tariff) was generated by escalating the TOC by a factor of 1.25. This factor was generated based upon the type of analysis of an airship operating company as reported in Appendix A of this report. The 1.25 factor represents the lower bound of the range of factors (1.25 - 1.61) generated based upon the type of analyses reported in Appendix A.

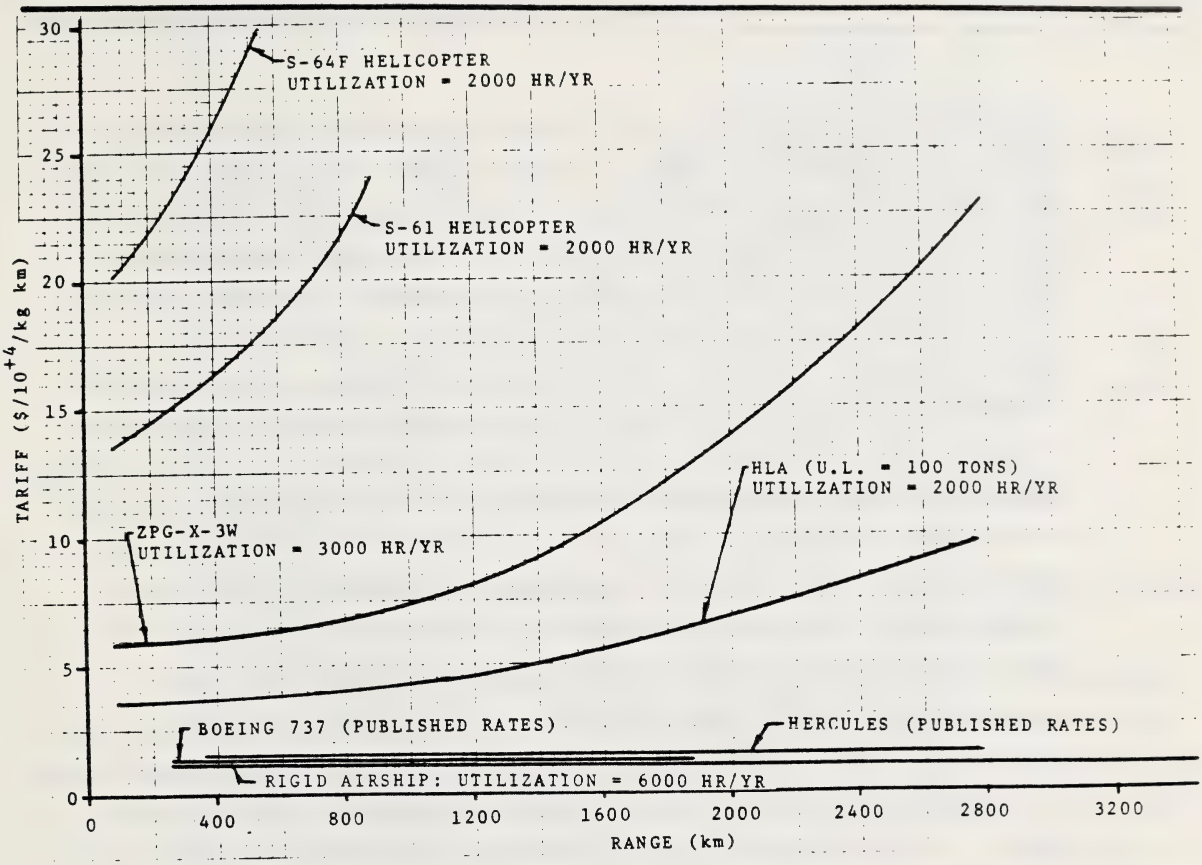


Figure 25 - Comparison Of Tariffs For Various Aircraft

It is impossible to ensure at this point that the 1.25 factor can be achieved. However, higher factors in most cases do not appreciably effect the economic potential indicated in the case studies for the airship.

4.4 Economic Case Studies (HLA)

The major purpose of this section is to document the economic advantage that modern airships offer in the study area. Additionally, based on the case study results and available reference material on expected economic growth (References 2 and 3), an estimate was made as to the number of airships that the study area could support.

It should be realized by the reader the case study applications are typical of those that exist and by no means do they represent the only applications which exist. It should also be realized that much of the data used in the case studies was obtained from surveys and it represents the best efforts of those who have provided it in terms of accuracy and explanation of its exact meaning to Goodyear. Under slightly different conditions, whatever they might be, the magnitudes of certain of the data provided might change noticeably. The reader may have different information available with respect to certain aspects of certain applications which he places higher confidence in than the data presented. If so, the reader should be able to assess the impact of his data in those cases based on the analyses provided herein.

It is obvious based upon the surveys conducted that there are many other types of applications, in which airships would show an economic advantage, than could be evaluated during this study. A significant factor impeding the study of additional applications is the task of the potential user developing sufficient data to permit the economic competitiveness of the airship to be identified. As additional evidence that the development of airships is proceeding becomes apparent to industries with potential applications, it is clear that there will be substantially increased interest in providing data permitting such analyses.

4.4.1 Typical Oil and Gas Industry Applications

4.4.1.1 Foothills Pipeline (Construction and Maintenance)

The Foothills Pipeline represents a major forthcoming project in the study area that serves well to illustrate the economic advantage of the HLA. The proposed pipeline route is indicated in Figure 26. The route generally parallels the Alaska Highway, a factor which might suggest that there would be little if any application for a special purpose aircraft during this project. However, it is apparent that there are several situations where the application of the HLA would result in considerable cost savings (by comparison to the expected costs for the methods currently planned for accomplishing the same task). These applications are discussed below.

4.4.1.1.1 Movement of Construction Equipment Across Rivers and Difficult Terrain

a) Primary Benefit of HLA - Reduced crew standby costs during movement of construction equipment across rivers.

b) Discussion of Application and Relevant Data - There are approximately twenty river crossings on the Canadian or Foothills portion of the pipeline that require circuitous routing of the construction equipment to transport it to the ROW on the opposite side of the river. Bridges in these cases are simply out of the question from the standpoint of distance and cost. The present plan (without the HLA) is to transport the equipment back down the completed ROW to the first existing road that leads to a suitable crossing. Once across the river, the first existing road back to the ROW will be taken and once at the ROW, the ROW will be used to transport the equipment to the river from where construction will proceed. (Note that construction across the river is handled independent of construction on either side of the river.)

Within Alberta, it appears that the circuitous routing would vary from a one-way distance of from 32 km (20 miles)

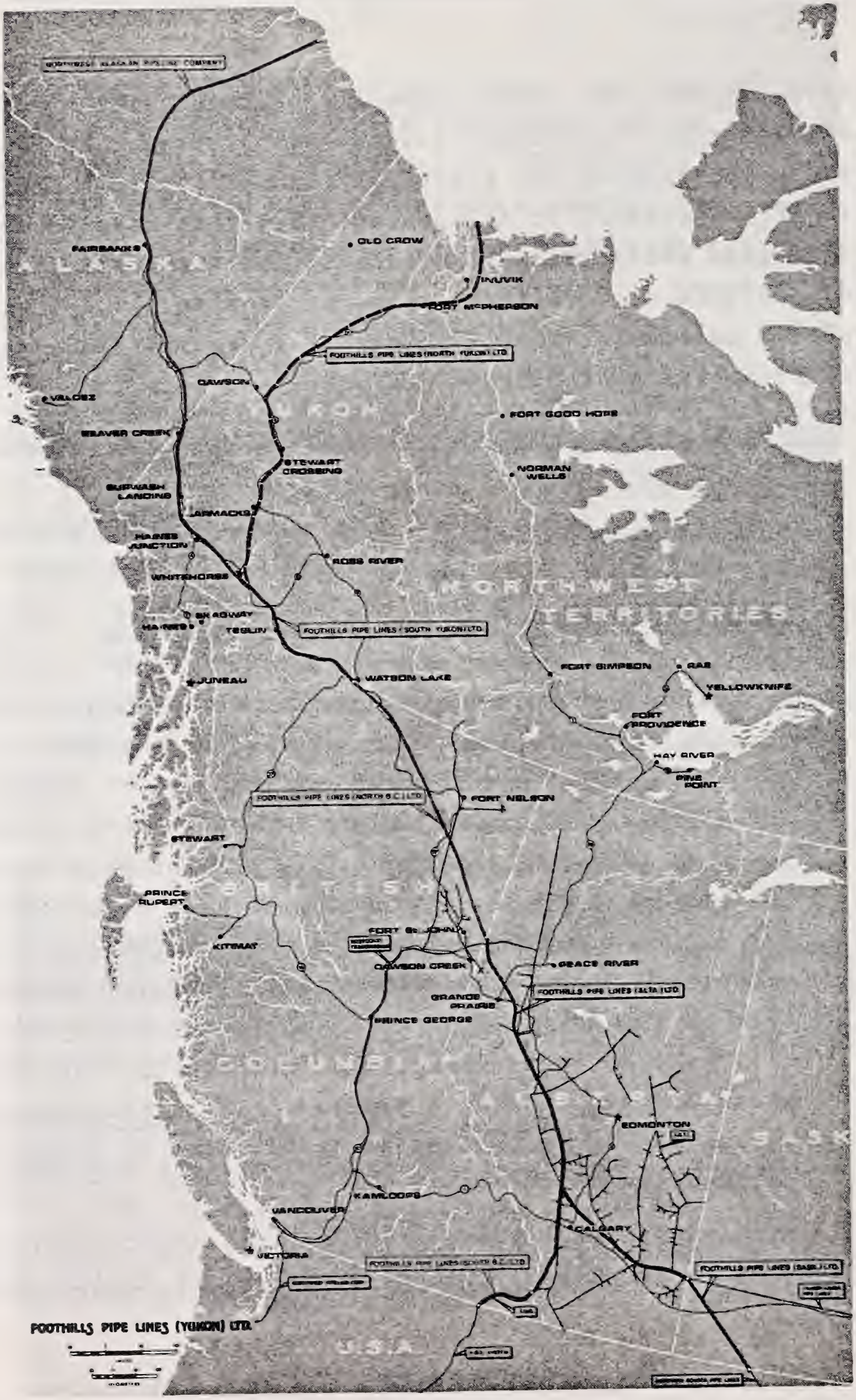


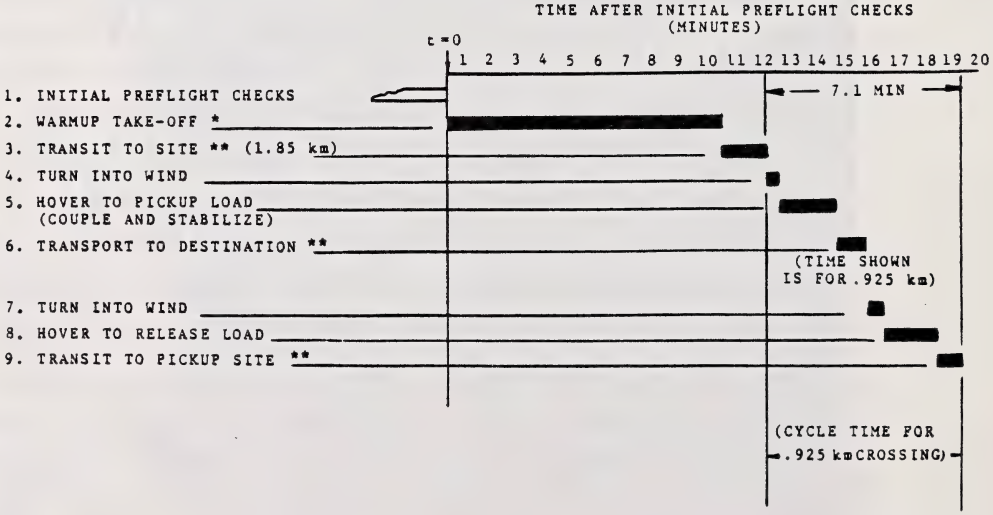
Figure 26 - Foothills Pipeline Route

minimum to 209 km (130 miles) maximum. For purposes of the following analysis an average one-way distance of 121 km (75 miles) has been considered. The nominal plan within Alberta suggests that there will not be a need to construct new or upgrade existing roads for hauling the heavy equipment. It does appear that in British Columbia there may be some considerable road building involved to transport the equipment to the opposite side of the river. Therefore, two cases are examined below: (1) one in which no road costs are considered; and (2) one in which it is assumed that, as an average, 10% of the total overland distance will require new roads at $6,220/km ($10,000/ mile).

It appears that it may be possible to average 48 km/h (30 mph) in transporting the equipment by truck. It is anticipated that there will be approximately ten trucks involved in moving the equipment and that the trucks would deadhead an average one way distance of 321 km (200 miles) (considering the entire Canadian route) to get to the ROW. Truck deadhead (mobilization) costs are figured on the basis of an average speed of 80 km/h (50 mph) at $35/HR for truck plus driver($0.47/km ($.75/mile). Truck costs (are $1.55/km ($2.50/mile) which covers an empty backhaul to the point where the equipment was loaded.

There are approximately 85 pieces of construction equipment that would require movement by the HLA. Movement by the HLA does not involve any precision placement requirements. Based upon hook up and release times for existing helicopters for non-critical pickup and placement of industrial equipment and components and computer simulation of the HLA acceleration and deceleration characteristics, it is anticipated that eight complete lifts can be completed per hour. Figure 27 presents the data on which the 8 lifts/HR is based. The figure presents a time line for a complete cycle involving the transport of construction equipment one-half nautical mile which is a representative transport distance for the rivers in question.

Based upon the above truck and distance parameters the span time for the move approaches 48 hours. Not all of this is lost time by the crew, however, because construction can begin at some level of efficiency prior to all equipment being moved. It appears to pipeline personnel that the use of the HLA can save one ten-hour shift per construction crew member, on the average. Based upon an average of 550 men/site at an average hourly expense of $30/HR this amounts to a crew standby loss of $165,000/crossing.



*ALL ENGINES, ROTORS AND PROPS ACTIVE

**INCLUDES CLIMB AND ACCELERATION TO 152.4 m, CRUISE (IF APPLICABLE) AT 152.4 m 148 km/h, DESCENT AND DECELERATION ($h_i = V_i = h_f = V_f = 0$)

Figure 27. Typical River Crossing Time Line

c) Discussion of HLA Requirements - It appears that a HLA with a 68,040 kg (75-ton) useful load capacity would handle the vast majority of equipment including the complete D594 pipelayer with counterbalances. There are a few pieces that would require a larger lift if the equipment were transported assembled. It is probably more cost effective to disassemble it and ship it in pieces than to consider a larger HLA. But to be conservative the following assumes an HLA with a useful load of 90,700 kg (100 tons) is required.

The hourly operating costs are based on the data of Table 7 and Paragraph 2.4.5 of Appendix B. The data in Paragraph 2.4.5 provides an allowance for the reduction in the rotor module maintenance costs that can be expected due to using current rotor system technology and a module designed specifically for the HLA. It is assumed that only 75% of the maximum improvement identified in Paragraph 2.4.5 can be achieved. The resulting hourly lift mode cost is $3,834/HR. The operating costs correspond to a production quantity of 25 vehicles and an annual utilization of 2000 HR. A round trip ferry distance for the HLA of 1851 km (1000 nm) is considered.

d) HLA Cost Benefit Summary

Case I (Assume no new road construction or road upgrading required)

1) Cost of HLA service/river crossing

Lift Mode Cost:

$$(85 \text{ Trips}) \left(\frac{\text{HR}}{8 \text{ Trips}}\right) \left(\frac{\$3834}{\text{HR}}\right) \left(\frac{1.25 \text{ RP}}{\text{TOC}}\right)^{*} = \$50,920$$

---

*Converts Total Operating Cost (TOC) to Rental Price (RP)

Ferry Mode (Mobilization) Cost: Round Trip Distance is 1851 km (1000 nm)

$$\left(\frac{1851\ \text{km}}{148\ \text{km/h}}\right)(\$3834/\text{HR})\left(\frac{1.25\text{RP}}{\text{TOC}}\right) = \$59{,}939$$

2) Truck Costs Saved/River Crossing

Mobilization Cost: (Round Trip Distance is 644km)

(644 km) ($.47/km) (10 Trucks = $3,027

Transport Cost: (One-Way Trip Distance is 121 km)

$$(85\ \text{Trips})\left(\frac{121\ \text{km}}{\text{Trip}}\right)\left(\frac{\$1.55}{\text{km}}\right) = \$15{,}942$$

3) Crew Stand-By Cost Savings/River Crossing:

$$(550\ \text{Men})(10\ \text{HR})\left(\frac{\$30}{\text{HR}}\right) = \$165{,}000$$

4) Cost Savings/River Crossing:

$165,000 + $15,942 + $3,027 - ($50,920 + $59,939)

= $73,110

5) Cost Savings for 20 River Crossings = $1,462,200

Case II (Assume 10% of total distance requires new roads at $6,215/km

1) Total kilometres of roads for 20 crossings:

(20 crossings)(121 km/crossing) = 2,420 km

2) New road costs for 20 crossings:

(2420 km)(.1)($6,215/km) = $1,504,030

3) Cost savings for 20 river crossings:

$1,462,200 (From Case I) + $1,504,030 (Road Costs)

= $2,966,230

4.4.1.1.2 Extension of Winter Construction Season

a) Primary Benefit

Reduction in number of winter sites.

b) Discussion of Application and Relevant Data

There are two cases analyzed below. The first case is based on the current diameter pipeline. The second case is based on a larger diameter pipeline which is currently under consideration.

Case I (Current Diameter Pipe)

The current construction plan involves completing all winter construction in one winter season. Currently, three winter sites are planned. The HLA is considered below as a means of reducing the number of winter sites from three to two. The estimated total cost for the total winter construction effort is $\$143 \times 10^6$.

There are an average of 550 men/site and the total winter labor requirement (3 sites) is estimated at 99,500 man days. This results in 60 days of actual construction activity during what is normally considered to be a 100-day season.

In the spring of the year before the thaw period sets in, the construction equipment must be moved from the winter site to the site where it is going to be used during the summer. If it is not moved prior to the thaw period, the roads cannot support the extreme loads and the equipment is trapped. The pipeline ROW could be worked considerably longer if it were not necessary to move the equipment out before road breakup. Construction personnel in Alberta estimate that a 20% extension of the normal winter season of 100 days is practical if the equipment could be moved out by air.

It should be noted that the 20-day extension that appears possible is 20 days of favorable weather where the efficiency of the construction crew will be considerably improved over their efficiency in the very cold portion of the winter. It appears reasonable to suggest that these 20 days of favorable working conditions could result in an increase in efficiency of 10% over the entire winter season. Combining the above, the available man days for the two sites can be considered to be:

$$(2 \text{ sites})(80 \text{ days})\left(\frac{550 \text{ men}}{\text{site}}\right)(1.1)^{*} = 96{,}800 \text{ man days}$$

This number is essentially the same number of man days presently planned for three winter sites. This is achieved with the same number of people per site, however, they work longer under slightly more efficient conditions.

There is a separate spread of equipment required at each of the three winter sites. The value of that equipment per spread is 18 to 20 million dollars. The cost to have that equipment at the construction site is approximately 5% of $\$19 \times 10^6$ per month. This is a monthly cost per site of $950,000.

For the current three site plan, three spreads of equipment are required for 100 days or a total cost for having the equipment at the sites of $9,500,000. For the plan in which the HLA is used the two sites of equipment is required for a total of 120 days. The cost for the two sites for 120 days is $7,600,000 which represents a cost savings of $1,900,000 which is attributable to the HLA.

In reducing the number of sites from three to two, the cost of mobilizing one complete site is avoided. Available

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[*] Overall increase in efficiency

data would suggest this savings would be approximately \$500,000.

There is typically a six-week period following the completion of the winter season prior to the time when construction can proceed on the summer site. During this period the construction personnel are typically laid off with the exception of the supervisory personnel. Supervisory personnel are assumed to comprise 10% of the total work force in the following analysis. By moving the construction equipment by the HLA, the supervisory personnel will be productive for twenty additional days which can be considered as a cost benefit attributable to the HLA.

It is conservatively assumed in the following analysis that the equipment must be transported by the HLA to the nearest railroad which is an average distance of 80 km (50 sm) from the winter sites. Based on a cruise speed of 148 km/h (80 knots) and time line considerations similar to Figure 26, it is anticipated that one round trip can be made every 1.5 hours.

Case I - HLA Cost Benefit Summary

1) Cost of HLA service for two sites

Lift Mode Costs:

$$(2 \text{ Sites})\left(\frac{85 \text{ Trips}}{\text{Site}}\right)\left(\frac{1.5 \text{ HRS}}{\text{Trip}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25 \text{ RP}}{\text{TOC}}\right)$$

$$= \$1{,}222{,}088$$

Ferry Mode (Mobilization) Costs:

$$\left(\frac{1851 \text{ km}}{148 \text{ km/h}}\right)(\$3834/\text{HR})\left(\frac{1.25 \text{ RP}}{\text{TOC}}\right) = \$59{,}939$$

Between Winter Sites

$\left(\frac{370\ \text{NM}}{145\ \text{km/h}}\right)(\$3834/\text{HR})\left(\frac{1.25\ \text{RP}}{\text{TOC}}\right) = \$11,981$

2) Site Mobilization Cost Savings: $500,000

3) Equipment Savings:

$\$9,500,000 - \$7,600,000 = \$1,900,000$

4) Supervisory Personnel Savings:

$(3\ \text{sites})\left(\frac{550\ \text{men}}{\text{Site}}\right)\left(\frac{1\ \text{Supervisor}}{10\ \text{Men}}\right)\left(\frac{10\ \text{HRS}}{\text{Day}}\right)$

$(20\ \text{days})\left(\frac{\$30}{\text{HR}}\right) = \$990,000$

5) Savings due to increase in crew efficiency:

(.1)[*] $(99,500\ \text{man days})\left(\frac{\$300}{\text{Man Day)}}\right) = \$2,985,000$

6) Neglect truck savings as they are minimal

7) Cost Savings for Case I:

$\$500,000 + \$1,900,000 + \$990,000 + \$2,985,000$

$- (\$1,222,088 + \$59,939 + \$11,981 = \$5,080,992$

Case II (Larger Diameter Pipe)

The construction plan for the larger diameter line calls for four sites and two winter seasons. The HLA is considered below as a means whereby the construction can be completed with three sites and one season.

The estimated value of winter construction for this plan is $\$167 \times 10^6$ as opposed to $\$143 \times 10^6$ for the smaller line. A rough estimate of the labor requirements for the larger line is obtained by multiplying the 99,500 man day labor estimate for the smaller line by the ratio of $\$167 \times 10^6/\$143 \times 10^6$. This suggests the labor requirement for the larger line is 116,200 man days. Considering

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[*] Increase in efficiency

80 working days as in Case I (60 days normal plus 20 days because of extension of season), for three crews in one season plus a 10% increase in overall efficiency, the available man days become:

(3 sites)(550 men/site)(80 days) = 132,000 man days

132,000 man days is more than the required 116,200 man days as defined above, thus the construction can be completed in one season with three sites instead of the current plan of two seasons and four sites.

Site mobilization costs will be reduced. Firstly, because there is no need for the fourth site (from Case I note that this represents a savings of \$500,000). Secondly, there is no need to mobilize the second season. This second season savings is considered to be only one-half (or \$250,000/site) of the initial site mobilization costs.

There are considerable equipment savings. Firstly, an entire two seasons (two hundred calendar days) is avoided on the equipment for the fourth site. This is a savings of: $(5\%/\text{month of } \$19 \times 10^6) = (\$.05)(200/30)(\$19 \times 10^6) = \$6,333,333$.

Secondly, instead of the equipment for the remaining three spreads being required for 200 days, it is required for only 120 days. This represents a savings of:

$$(3)(.05)\left(\frac{200-120}{30}\right)(\$19 \times 10^6) = \$7,600,000$$

There will also be a savings due to the supervisory personnel being productive for an additional 20 days just as in Case I. The savings is the same as in Case I.

The savings due to an increase in crew efficiency is 10% of the cost of the planned labor requirement of 116,200 man days at \$300/day. This totals \$3,486,000.

There will also be a savings in project investment costs when using the HLA due to the project being completed in one season instead of two. The following analysis assumes 1% per month for the cost of money and a linear spend plan in order to obtain a first order estimate of the type of investment savings that will occur. The $\$167 \times 10^6$ project costs (without HLA) are considered to be financed over 16 months (start of one winter season to completion of next) and the finance period for the plan using the HLA is considered at 4 months (one winter season).

Based on the above, the finance charges on $\$167 \times 10^6$ over 16 months appear to be about $\$13.5 \times 10^6$. The finance charges on the project if the HLA were used are estimated at $\$3.5 \times 10^6$ which represents a savings of $\$10 \times 10^6$.

Case II HLA Cost Benefit Summary

1) Cost of HLA service for three sites

Lift Mode: (See Case I for origin of HLA parameters)

$$(3\ \text{sites})\left(\frac{85\ \text{trips}}{\text{site}}\right)\left(\frac{1.5\ \text{HRS}}{\text{trip}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25\ \text{RP}}{\text{TOC}}\right)$$

$$= \$1,833,131$$

Ferry Mode:

From Permanent Base

$$\left(\frac{1853\ \text{km}}{148\ \text{km/HR}}\right)(\$3834/\text{HR})\left(\frac{1.25\ \text{RP}}{\text{TOC}}\right) = \$59,939$$

Between Winter Sites

$$(2\ \text{trips})\left(\frac{370\ \text{km}}{\text{Trip}}\right)\left(\frac{1}{148\ \text{km/h}}\right)(\$3834/\text{HR})\left(\frac{1.25\ \text{RP}}{\text{TOC}}\right)$$

$$= \$23,962$$

2) Site Mobilization Cost Savings
Savings because fourth site not required = \$500,000.

Savings because there is no need to return to any of the sites the second year = 4 (250,000) = \$1,000,000.

3) Equipment Savings = \$6,333,333 + \$7,600,000 = \$13,933,333.

4) Supervisory Personnel Savings (Same as Case I) = \$990,000.

5) Savings due to increase in crew efficiency =

$$(.1)^{*} \text{ (116,200 man days)}\left(\frac{\$300}{\text{man day}}\right) = \$3,486,000.$$

6) Neglect truck savings as they are small.

7) Project Investment Savings = $\$10 \times 10^6$

8) Cost Savings for Case II =
\$500,000 + \$1,000,000 + \$13,933,333 + \$990,000 + \$3,486,000 + \$10,000,000 - (\$1,833,131 + \$59,939 + \$23,962) = \$27,992,301.

4.4.1.1.3 Modular Construction of Compressor Stations

a) Primary Benefit
Reduced heavy haul road construction costs and reduced in-field assembly costs.

b) Discussion of Application and Relevant Data
There are approximately 20 compressor stations on the Canadian portion of the pipeline. There are approximately 1,814,400 kg (2000 tons) of material that must be moved in per station. There are two or three pieces of 45,372 kg (50-ton) operating equipment that must be moved in that necessitate construction of what are termed "heavy haul

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[*] Increase in efficiency

roads". These roads represent a nominal $750,000 delta cost per station over the normal access road that can handle a normally loaded truck at 18,144 to 22,680 kg (20 to 25 tons). The average length of these heavy haul roads is on the order of 40.23 km (25 miles).

Foothills has also made a study of the benefits of modularizing compressor stations in 45,372 kg (50 ton) modules since the heavy haul roads are required. These analyses indicate a nominal savings of $175,000 in going from a 227 kg (25-ton) module to a 45,372 kg (50-ton) module.* This is due to more efficient conditions, lower wages, etc. prevailing in the factory environment in comparison to field assembly conditions. For purposes of the following analysis, it is assumed that modularizing to 68,058 kg (75 tons) represents an additional savings of $175,000 in comparison to 45,372 kg (50-ton) modules. For purposes of this analysis it is assumed that 68,058 kg (75-ton) modules would be moved in. Thus, there are a total of 8 moves per compressor station considered below.

By using the HLA, the heavy haul road costs can be avoided, and, in addition larger loads can be moved thus increasing the benefits of modularization. As in the previous case studies, an HLA with a 45,372 kg (50-ton) useful load is considered and the hourly costs are as before.

It is anticipated, based upon an 148 km/h (80-knot) cruise speed, that it will require approximately .75 hour per lift to pickup, transport, and release the 68,058 kg (75-ton) modules. There is no precision placement involved, however, the operating equipment at this time must be regarded as more fragile than the construction equipment moved in the prior case studies.

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*Note compressor station total cost in the $\$5 \times 10^6$ to $\$6 \times 10^6$ range.

Accordingly, allowances have been made for this factor in arriving at pickup and release times. The return trip of 40 km (25 miles) to acquire a new load is estimated to require .35 hour. Thus, the round trip flight time is estimated to be 1.1 hours.

c) HLA Cost Benefit Summary

1) Cost of HLA Service Per Compressor Substation

Lift Mode Cost: (40 km one-way distance)

$$(8 \text{ trips})\left(\frac{1.1 \text{ HRS}}{\text{trip}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25 \text{ RP}}{\text{TOC}}\right) = \$42{,}174$$

Ferry Mode Cost: (1851 km/compressor station)

$$\left(\frac{1851 \text{ km}}{148 \text{ km/h}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25 \text{ RP}}{\text{TOC}}\right) = \$59{,}939$$

2) Road Cost Savings Per Compressor Station = $750,000.

3) Savings Due to Modularization Per Compressor Station:

$$\left(\frac{5 \text{ modules}}{\text{station}}\right)\left(\frac{\$175{,}000}{\text{module}}\right) = \$875{,}000$$

4) Cost Savings Per Compressor Station:

$$\$750{,}000 + \$875{,}000 - (42{,}174 + 59{,}939) = \$1{,}522{,}887.$$

5) Cost Savings for Twenty Compressor Stations:

$$20\ (\$1{,}522{,}887) = \$30{,}457{,}740$$

4.4.1.1.4 Emergency Repair of Pipeline

a) Primary Benefit

Reduction in lost revenues by reducing time required to effect line repair.

b) Discussion of Application and Relevant Data

When a line break occurs or when thruput is reduced due to loss of a compressor station, the daily loss in revenues are very large. The daily thruput of the currently planned line will be on the order of 71 x 10^9 m^3 (2 x 10^9 cu ft) of gas per day. At $3.00 per 35,315 m^3 (1000 cu ft) of gas this represents a revenue of $6 x 10^6. If a break occurs, the line is completely shut down and the lost revenues total $6 x 10^6. If a compressor station is lost, given 20 stations on the line, the loss in revenue, due to reduced thruput is 1/20 of $6 x 10^6 or $300,000.

Discussions with Foothills personnel indicate that it is reasonable to expect that the HLA can reduce the time to repair a line break or a reduction in thruput by one day. The HLA is used to move in heavy equipment and repair materials quicker than can be accomplished by conventional truck and, of course, this can be done independently of road conditions.

The HLA will be required to move the equipment and materials 185 km (100 mi). It is also assumed that the HLA will be required to remove the heavy equipment. To repair a line break two pieces of heavy equipment and one load of pipe will be needed. This involves four 185 km (100-mile) round trips and one 185 km (100-mile) one-way trip.

Again the size and hourly costs for the HLA remain the same as in the previous case studies. It is anticipated that the trip distance of 185 km (100 miles) is sufficiently long that the rotor systems would not be operated on the return trip to acquire a new load. Based upon a cruise speed of 148 km/h (80 knots) and a lack of precision placement requirements it appears that the one-way trip of 185 km (100 miles) will require approximately 1.5 hours. The return trip (empty) will require on the order of 1.2 hours.

It has been assumed for purposes of current analysis that repair of a compressor station will involve two heavy lifts each 185 km (100 miles) in length with similar trip times to those above.

c) HLA Cost Benefit Summary (Line Break)

1) HLA Cost

Lift Mode

Transport:

$$(3\text{ trips})\left(\frac{1.5\text{ HRS}}{\text{Trip}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25\text{ RP}}{\text{TOC}}\right) = \$21,566$$

Return:

$$(3\text{ trips})\left(\frac{1.2\text{ HRS}}{\text{Trip}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25\text{ RP}}{\text{TOC})}\right) = \$17,254$$

Ferry Mode (1851 km Round Trip):

$$\left(\frac{1851\text{ km}}{148\text{ km/h}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25\text{ RP}}{\text{TOC}}\right) = \$59,939$$

2) Savings in Lost Revenues: $\$6 \times 10^{6}$

3) Cost Savings:

$$\$6 \times 10^{6} - (\$21,566 + \$17,254 + \$59,939) = 5.9 \times 10^{6}$$

d) HLA Cost Benefit Summary (Reduced Thruput)

1) HLA Cost

Lift Mode

Transport:

$$(2\text{ trips})\left(\frac{1.5\text{ HRS}}{\text{Trip}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25\text{ RP}}{\text{TOC}}\right) = \$14,378$$

Return:

$$(2\text{ trips})\left(\frac{1.2\text{ HRS}}{\text{Trip}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25\text{ RP}}{\text{TOC}}\right) = \$11,502$$

Ferry Mode (Same as above):

$59,939

2) Savings in Lost Revenues: $300,000

3) Cost Savings:
$300,000 - ($14,378 + $11,502 + $59,939) = $214,181

Although the Foothills pipeline has been considered on a case study basis, the proposed Polar Gas Line which would bring gas from the Arctic Islands down the West side of Hudson Bay is perhaps a better example in terms of indicating a larger savings by use of the HLA. The Polar Gas project is faced with a situation of few existing roads from which to build and maintain the pipeline. They also have periods of the year when the soil cannot support movement of heavy equipment. Thus, the HLA in a situation such as this could save considerably more than one day.

It should be realized that although great benefit can be projected for the HLA in a line break situation, line breaks occur infrequently. Therefore, the servicing of line breaks cannot be expected to create a market. The device is so attractive, however, when a break does occur that it appears pipeline operators would offer a substantial annual retainer to have the device available when needed on a priority interrupt basis. In the case of Polar Gas, it might significantly reduce the equipment material inventory costs associated with maintaining the pipeline.

4.4.1.2 Polar Gas Pipeline Project

The proposed Polar Gas Pipeline (see Figure 28) is another large project within Canada that can be used to illustrate the economic advantage that the HLA can offer. This project has certain applications that are similar to the previous case study results presented for the Foothills Project and

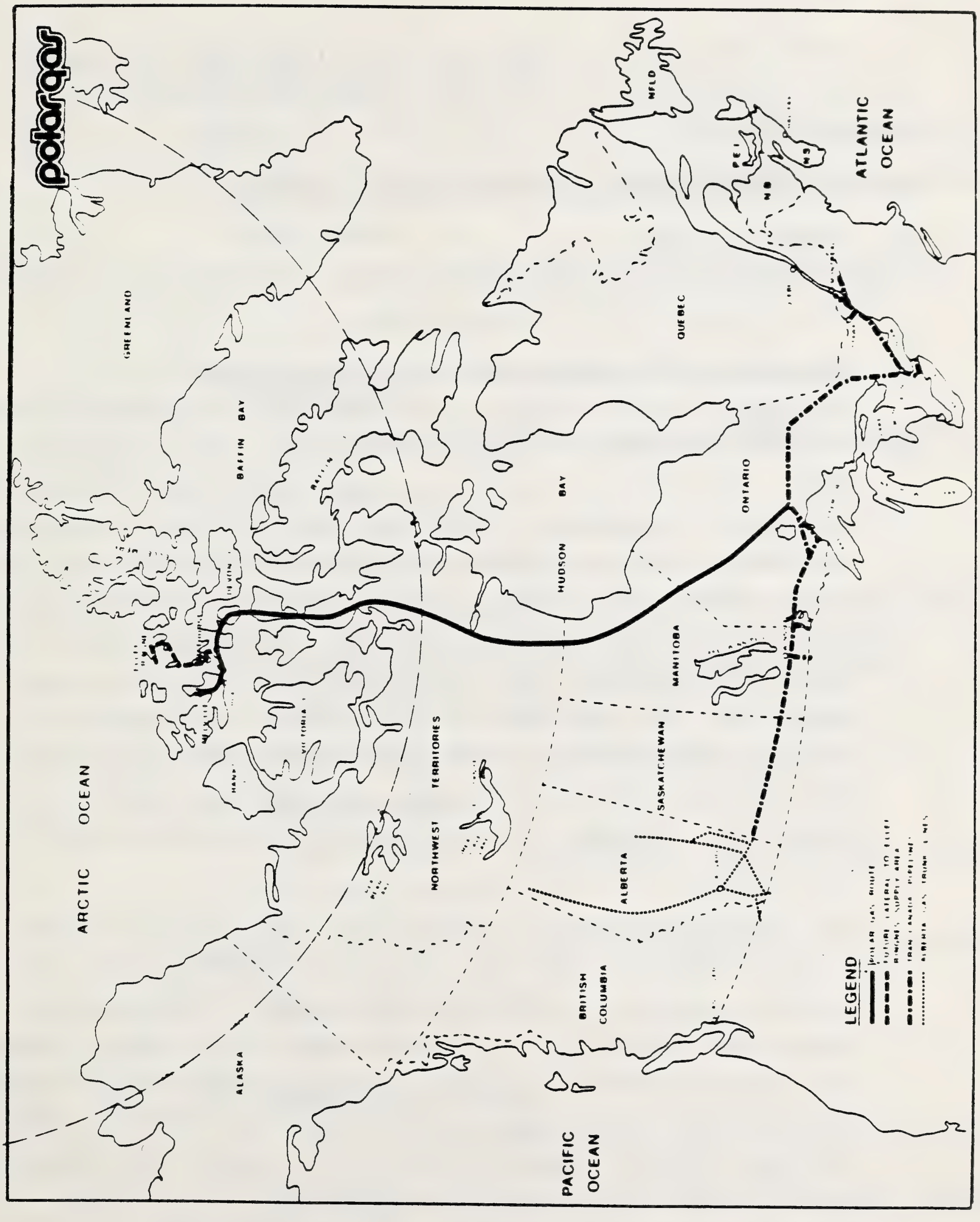

Figure 28 - Polar Gas Pipeline Route

as a result details of these are not presented. A slightly different application than those considered previously is discussed below.

4.4.1.2.1 Movement of Equipment Between Arctic Islands

a) Primary Benefit

Prevent entrapment of construction equipment on Islands after completion of construction.

b) Discussion of Application and Relevant Data

The construction season in the High Arctic typically begins in early May and ends in late October. Ice conditions constrain the barging season to a period between mid-July and the end of September. Ice conditions between islands may not permit the heavy equipment to be moved over the ice to the next island. Thus, equipment may be trapped unproductively for extended periods. Dependent on how construction proceeds, use of the HLA can save the costs associated with one spread of equipment (80 pieces) for a minimum of 22 months and a maximum of 42 months for the four islands involved. Equipment costs per month for a spread of equipment is approximately 6% of \$20 x 10^6 or \$1.2 x 10^6.

The distance between islands varies from 5.5 to 65 km (3 to 35 miles). For the four moves involved, the average distance appears to be 37 km (20 miles). The average round trip time will be on the order of .75 hour. There will be four separate moves, thus the total ferry distance involved in calculating the HLA costs is 7400 km (4,000 nautical miles). Again, an HLA of a useful load capacity of 90,744 kg (100 tons) is considered with the same operating costs of the previous case studies.

c) HLA Cost Benefit Study

Case I (22 month savings in one spread of equipment)

1) Cost of HLA service (4 moves between islands)

Lift Mode:

$$(4 \text{ moves})\left(\frac{80 \text{ trips}}{\text{move}}\right)\left(\frac{.75 \text{ HR}}{\text{trip}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25 \text{ RP}}{\text{TOC}}\right)$$

$$= \$1{,}150{,}200$$

Ferry Mode:

$$(4 \text{ trips})\left(\frac{1851 \text{ km}}{\text{trip}}\right)\left(\frac{1}{148 \text{ km/h}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25 \text{ RP}}{\text{TOC}}\right)$$

$$= \$239{,}626$$

2) Equipment Savings:

$$(22 \text{ months})\left(\frac{6\%}{\text{month}}\right)(\$20 \times 10^6) = \$26{,}400{,}000$$

3) Investment savings on equipment costs are approximately $\$3 \times 10^6$

4) Neglect savings in barge costs

5) Cost Savings:

$$\$26{,}400{,}000 + \$3{,}000{,}000 - (\$1{,}150{,}200 + \$239{,}626)$$
$$= \$28{,}010{,}174$$

Case II (42 months savings in one spread of equipment)

1) Cost of HLA service:

Same as above

2) Equipment Savings:

$$(42 \text{ months})\left(\frac{6\%}{\text{month}}\right)(\$20 \times 10^6) = \$50{,}400{,}000$$

3) Investment savings on equipment costs are approximately $\$12 \times 10^6$

REF: EOI 380

4) Neglect savings in barge costs.

5) Cost Savings:

$$\$50{,}400{,}000 + \$12 \times 10^6 - (1{,}150{,}200 + 161{,}938)$$
$$= \$61{,}087{,}862$$

4.4.1.2.2 Other Polar Gas Applications

Due to a lack of an existing surface infrastructure and a limited barging season, it is clear that the Polar Gas Pipeline Project has an extensive number of additional HLA and modern conventional airship applications. Polar Gas intends to use S-61 and S-64 helicopters for these priority situations. Data presented in Section 4.3 indicated the significant cost savings that would occur in using the HLA. The HLA also permits much larger payloads which will offer other economic benefits. At this point however, sufficient data has not been generated to illustrate this point.

4.4.1.3 Oil and Gas Drilling in Remote Areas

a) Primary Benefit

Reduced transportation and site operating costs in comparison to helicopters.

b) Discussion of Application and Relevant Data

In areas where an adequate road infrastructure is available, the drilling rig equipment and supplies are transported in by truck. Most of the oil and gas reserves located in easily accessible regions with an adequate road network have already been explored and are currently in the production stage. Increasingly, the oil companies are forced to explore for oil and gas and drill in remote areas with no or limited transportation infrastructure. For oil and gas drilling operations the helicopter has proven itself to be an efficient and viable means of transportation and the drillers have adapted their operations to the capabilities of the helicopters.

The type of helicopters normally used for remote drilling operations are:

- Bell 205 - payload capacity 1,818 kg (4,000 pounds)
- Bell 215 - payload capacity 1,932 kg (4,250 pounds)

The cost of chartering these helicopters ranges from $400 to $500 per hour.

In a typical remote drilling operation a staging area is established next to a barge landing, road or railroad spur. The rig, all equipment and supplies are unloaded from the conventional means of transportation at this staging area.

The average distance from the staging area to the drill site is 50 km (30 miles). The following equipment and supplies are moved by helicopter in 1,818 kg (4,000 pound) increments from the staging area to the drill site:

1) Drilling Rig

The drilling rig has been constructed so that it can be dismantled into 1,818 kg (4,000 pound) modules. A total of 110 to 115 lifts each of 1,818 kg (4,000 pounds) would be required. Total:199,637 to 208,711 kg (440,000 to 460,000 pounds). Note that the largest practical module size for transporting rig appears to be approximately 22,686 kg (25 tons).

2) Drill Pipe

Total quantity required:

- 500 lengths drill pipe and drill collar .114 m 9.35 m (30 foot) length - each 227 kg (500 pounds)
  Total: 113,430 kg (250,000 pounds)
- 40 drill joints - each 1,815 kg (4,000 pounds)
  Total: 72,595 kg (160,000 pounds)

3) Drill Casing

- 914 to 1,219 m (3,000 to 4,000 foot) casing - weight: 80 kg/m (54 pounds/foot).
  Total: 72,595 to 99,818 kg (160,000 to 220,000 pounds)
- 3,200 m (10,500 foot)×.24 m (9-5/8 inch) casing - weight: 47 kg/m (32 pounds/foot).
  Total: 152,400 kg (336,000 pounds)
- 4,267 - 4,572 m (14,000 - 15,000 foot)×.2 m (7-7/8 inch) casing
  weight: 43 kg/m (29 pounds/foot).
  Total: 183,707 - 197,315 kg (405,000-435,000 pounds)

4) Fuel

The drill jig consumes 13.6 kg (30 pounds) fuel per day, and the total time of operation is 45 days up to 120 days. The fuel is brought to the site in a rubber bladder. Weight of the bladder is 113 kg (250 pounds) empty and holds 1,814 kg (4,000 pounds) of fuel and the total weight is 1,928 kg (4,250 pounds).

5) Crane

A 2,268 kg (5,000 pound) capacity crane is brought into the site. This crane is dismantled, brought to the site and disassembled. Weight of the crane is approximately 3,629 kg (8,000 pounds).

The total weight, which the helicopter has to transport to the site is therefore between 799,619 kg and 849,587 kg (1,763,000 pounds and 1,873,000 pounds). The helicopters have to make between 440 and 460 trips to carry the equipment and supply requirements to the site.

Once the drilling operation is concluded the rig and the crane have to be transported out again. This will require another 110 to 115 lifts. Total lifts for the project will therefore be between 550 and 585 lifts.

Assuming that each round trip will require an average of 45 minuts of flying time, and that the project is charged only for actual flying time, the transport costs for the helicopter is expected to be between $165,000 and $219,000.

With continuous operation eight hours per day it will take the helicopter at least 10 days to bring the rig to the site, and another 10 days to take it from the site at the completion of the drilling operation. This is based upon eight-hour day continuous operation by the helicopter, which according to a driller with extensive experience using helicopters, is reasonable. The total cost to the driller both during the transportation and assembly of the rig and supplies, and during drilling operations is $15,000 to $20,000 per day. The costs are the same whether drilling is performed or not, because in both cases all personnel and support services are required.

The 90,718 kg (100-ton) useful load HLA considered in previous case studies can complete the movement of the drill rig, 199,581 to 208,652 kg (220 tons to 230 tons), to the site in less than 8 hours flying time in 22,679 kg (25-ton) increments. Similar expediency can be achieved in removing the rig. Thus, a minimum savings of 18 days, at $15,000 to $20,000 per day, can be realized by using the HLA.

The HLA requires the following number of lifts (payload is 75,296 kg, 83 tons):

1) Drill Rig[*] - 9 lifts of 22,679 kg (25 tons each)
2) Drill Pipe - 2 lifts of 57,000 kg (62.5 tons each)
3) Drill Joints - 1 lift of 72,575 kg (80 tons)
4) Drill Casing - 6 lifts of 75,296 kg (83 tons)

The total number of lifts is 18. HLA costs are as indicated in the previous case studies. A round trip time for the HLA of 0.75 hour is considered.

a) HLA Cost Benefit Summary

1) HLA Costs:

Lift Mode

$$(18 \text{ trips})\left(\frac{.75 \text{ HR}}{\text{trip}}\right)\left(\frac{\$3834}{\text{HR}}\right)\left(\frac{1.25 \text{ RP}}{\text{TOC}}\right) = \$\ 64{,}698$$

Ferry Mode - 1851 km (1000 nm) round trip distance

$$\left(\frac{1851 \text{ km}}{148 \text{ km/h}}\right)(\$3834)\left(\frac{1.25 \text{ RP}}{\text{TOC}}\right) = \$59{,}939$$

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[*] Fuel plus crane would be carried during one or more of these lifts also.

2) Helicopter Costs: $165,000 to $219,000

3) Savings in Site Operations costs

Minimum: (18 days)($15,000/day) = $270,000
Maximum: (18 days)($20,000/day) = $360,000

4) Cost Savings:

Minimum

$270,000 + $165,000 - ($64,698 + $59,939) = $310,363

Maximum

$360,000 + $219,000 - ($64,698 + $59,939) = $454,363

4.4.2 General Construction Industry Applications

Major resource projects are becoming more and more remote simply because it is human nature to process readily available resources first. The trend will obviously continue. Major remote projects in the world ($\$200 \times 10^6$ and greater) may currently number up to 300. As the world population continues to increase and as time passes, the number of remote projects will undoubtedly increase, at least for some substantial period of time into the future.

In Goodyear's surveys of the largest constructors of these remote projects, there was a prevalent thought put forth that the HLA has applications in the initial portions of nearly all remote projects. The application of the HLA was directed primarily at reducing project span time and therefore project investment costs as well as getting the facility "on stream" earlier and revenues in the operators' hands earlier. These comments prompted a very general case study based upon a hypothetical parametric construction project which is reported in Section 4.4.2.1 below. That case study considers the cost benefit of an HLA purely from a standpoint of project investment cost savings that may be possible. The primary use of the HLA was in moving heavy equipment in very early in the project before roads, docks, ports, bridges, camps. etc., were built which normally delay start of the heavy construction.

Another benefit that is obvious in the consideration of the HLA to the general construction industry is that which accrues due to modularization (i.e., reduction of in-field assembly requirements by moving operating equipment, etc., to the construction site at a higher level of assembly). Nearly all constructors cite the benefit of the HLA in that type of application. An attractive feature of such an application to an operator of an airship service is that it cuts across all types of construction projects. Thus it is reasonable to suspect that a substantial market can be expected to exist. Unfortunately, it is a substantial task for a constructor to bring together the appropriate project estimators, etc. to structure a cost benefits study. As mentioned earlier, additional evidence that development of such a device is a real probability will undoubtedly increase their detailed evaluation of the economic merits of the device. At this point, however, sufficient data are not available to structure a "hard" case study.

4.4.2.1 Early Movement of Construction Equipment to Remote Projects

(a) Primary Benefit

Reduction in project investment costs by reducing project span time.

(b) Discussion of Application and Relevant Data

A hypothetical project has been set up on a parametric basis which permits the savings in project investment costs to be defined as a function of project size and and the percent reduction in span time achieved. The percent reduction achieved will be highly dependent upon the specifics of the remote project. It is believed the range of span time savings considered herein encompasses most projects.

For every \$100 x 10^6 of project value it has been assumed that 50 pieces of heavy equipment must be transported (100 miles) each. This is probably a conservative number of pieces in that quite often to get a project started less equipment may be needed.

Project values from \$50 x 10^6 to \$750 x 10^6 were considered. Project span time savings from 5 to 25% were considered. In all cases the project span time without HLA was considered to be three years.

Again, an HLA with a useful load of 90,744 kg (100 tons) was considered with the hourly costs presented in earlier case studies. A round trip ferry distance of 1851 km (1000 nm) has again been considered.

Figure 29 graphically illustrates the cost benefit of the HLA in this application. Note that the cost benefit is simply the total investment minus the cost of the HLA service.

4.4.3 Power Generation Industry

There are a large number of power generation applications for the HLA on a world-wide basis. There is, of course, no foreseeable end to the ever-growing requirement for additional power generation facilities and attendant distribution networks. The HLA has application in the construction of both power generation facilities (fossile fuel, nuclear and hydroelectric) as well as the distribution networks for each.

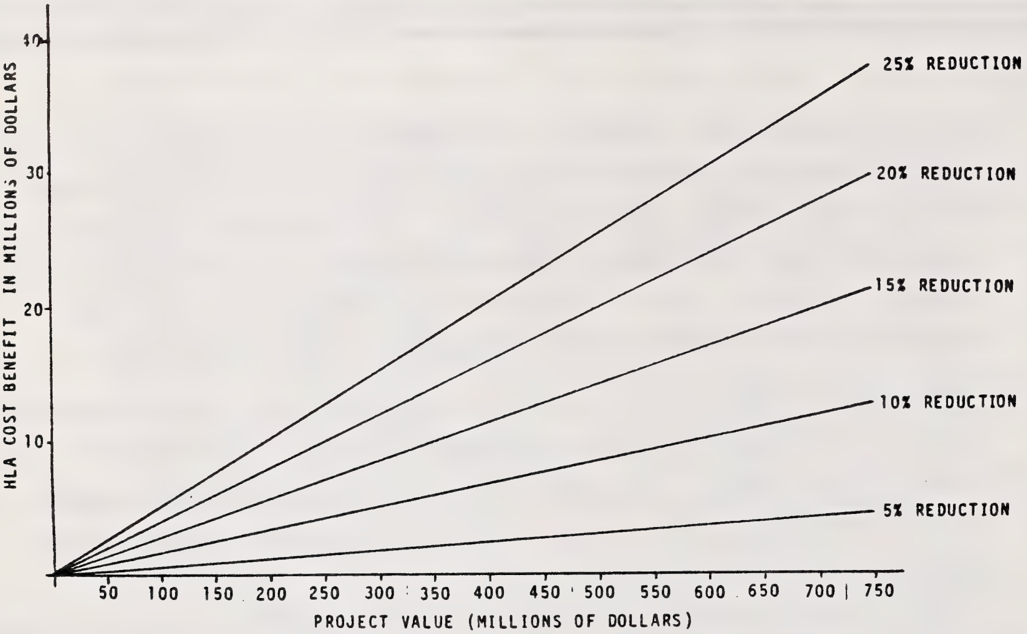

Figure 29 - Cost Benefit Of HLA As A Function Of Percent Reduction In Project Span Time And Project Value

The applications of the HLA to construction of power generation facilities can involve extremely large components, 272,232-907,441 kg (300 - 1000 tons). The current costs of moving these components including associated infrastructure costs can be extremely large. Large HLA's once develped would most certainly have application to these requirements. Appendix B illustrates that as the size of the HLA increases the cost per ton mile does not change significantly for similar quantities of vehicles. Data are available for case studies in this area, however, this application is considered only of academic interest with respect to the objectives of this study. The reason that these large HLA vehicles are not near term is due primarily, to an inability, at present, to show sufficient quantity demand to amortize the development costs and to achieve meaningful learning curve effects in the manufacturing process. Therefore the likelihood of the larger vehicles being available in the foreseeable future is considered remote.

An application in the power generation industry that has extensive need of the HLA services is the erection of power line transmission towers. Two separate case studies are considered below. The initial study considers a savings in road costs for a line constructed in very difficult terrain. The second study considers a line completed under more normal terrain conditions where road costs do not formulate a high percentage of the total project costs.

4.4.3.1 Erection of Transmission Towers in Difficult Terrain

Primary Benefit

Reduction in total project costs due to a reduction in: investment costs as a result of reduced project span time; infield labor requirements; and road costs.

Discussion of Application and Relevant Data

When construction transmission lines in difficult terrain, one-half the total project cost can be the result of the need to construct heavy haul roads. Use of the HLA to move the heavy equipment from tower site to tower site can reduce road costs considerably. Roads would still be required to carry in concrete, tower materials, etc. The following study considers a reduction in road costs of 50%. This seems reasonable in view of the fact that the heavy equipment plus truck may weigh 45,372 kg (50 tons) whereas large concrete trucks fully loaded weigh on the order of 18,149 kg (20 tons) as do flatbeds hauling other construction materials.

A transmission line 96 km (60 miles) long (some are hundreds of kilometres long through mountainous country) with 240 towers, each weighing 36,298 kg (40 tons), has been considered. Note that 36,298 to 45,372 kg (40 to 50-ton) towers are not uncommon at all with some towers weighing up to 108,892 kg (120 tons). Conventional methods in difficult terrain typically result in project costs of \$5.51/kg (\$2.50/lb) of tower weight. Therefore, the project costs for the case study example is \$48 x 10^6. Manpower requirements using conventional methods are:

Pre-assembly costs (staging area) = 45.3 kg (100 lb) of tower/manhour

Erection costs (one 36,298 kg, 40-ton tower) = 10 days for 12 man crew

Road costs can comprise 50% of the total project costs for projects in difficult terrain or \$24 x 10^6 in this case. The total project span time for the 96 km (60-mile) line would typically be 18 months.

It is conservatively anticipated that tower erection labor requirements can be reduced by 25% based upon discussions with tower constructors. This results in the following savings based on the above data:

$$25\%\left(\frac{240 \text{ towers}}{.1 \text{ tower/crew/day}}\right)\left(\frac{12 \text{ men}}{\text{crew}}\right)\left(\frac{10 \text{ hrs}}{\text{man/day}}\right)\left(\frac{\$28}{\text{hr}}\right)=\$2,016,000$$

An additional savings attributal to the HLA is that associated with the rental of the normally required crane to assist in the tower erection. Of course, with the HLA the crane will not be required. Crane costs are on the order of \$67/hr plus \$18/hr for the operator. Based upon a normal operator, the savings in this areea are:

$$10 \text{ months} \left(\frac{160 \text{ hrs}}{\text{month}}\right)\left(\frac{\$18 + \$67}{\text{hr}}\right) = \$136,000$$

An HLA with a useful load of 45,372 kg (50 tons) is considered for this application. From Appx B, the hourly TOC is $2,147. This hourly cost reflects an estimate of the improvement in rotor module maintenance costs that can be expected due to using current rotor systems technology and a module designed specifically for the HLA. The operating costs are based upon a production quantity of 25 vehicles and 2000 hr/yr utilization.

In supporting the construction of the tower foundations, the HLA will be required to make three lifts/foundation to move the heavy equipment. These moves will average 0.40 km (0.25 mi) each and would require only a few minutes each. However, since this phase will require eight months of span time to complete for other reasons, the HLA costs are based upon having the vehicle available to the project the entire period. This is somewhat conservative since fuel and maintenance costs would only be applicable to the actual operating hours. Based upon conversations with power line constructors the erection of the towers will require sixty (60) hours of the HLA services based upon the experience of setting smaller towers with helicopters.

Conservatively, the cost of the HLA is equivalent to 8.38 months of rental plus ferry costs, or:

Lift Mode:

$$\left(\frac{8.38\ \text{months}}{12\ \text{mon/yr}}\right)\left(\frac{2000\ \text{hr}}{\text{yr}}\right)\left(\frac{\$2147}{\text{hr}}\right)\left(\frac{1.25\ \text{RP}}{\text{TOC}}\right) = \$3,748,304$$

Ferry Mode:

$$\left(\frac{1551\ \text{km}}{148\ \text{km/h}}\right)\left(\frac{\$2147}{\text{hr}}\right)\left(\frac{1.25\ \text{RP}}{\text{TOC}}\right) = \$33,547$$

Total HLA cost = $3,781,850.

Investment savings based on reducing the total project span time form 18 to 13 months and an interest rate of 1%/month are on the order of $2,100,000.

HLA Cost Benefit Summary

1) HLA Costs = -\$3,781,850
2) Crane Cost Savings = + 136,000
3) Erection Cost Savings = + 2,016,000
4) Investment Cost Savings = + 2,100,000
5) Road Cost Savings
50% (\$24 x 10^6) = +12,000,000
6) Cost Savings Summary = +12,470,150

4.4.3.2 Erection of Transmission Towers in Good Terrain Conditions

a) Primary benefit

Reduction in total project costs due to a reduction in investment costs as a result of reduced project span time and in-field labor requirements.

b) Discussion of Application and Relevant Data

The problems and cost of constructing a power transmission line under what is termed good terrain conditions are much less than under difficult conditions. However, under these more favorable conditions the HLA nevertheless shows considerable economic benefit in comparison to conventional methods.

Typical parameters for a line constructed over normal terrain are:

1) Project costs are \$0.55/kg (\$0.25/lb) of tower weight
2) One tower erected/day/12 man crew
3) Pre-assembly (staging area) = 45.36 kg (100 lb) of tower/manhour

Thus, the total project costs are:

$$\left(\frac{\$0.55}{\text{kg}}\right)(240\ \text{towers})\left(\frac{36{,}298\ \text{kg}}{\text{tower}}\right) = \$4{,}800{,}000$$

Again, tower erection labor requirements can conservatively be reduced by 25% resulting in the following:

$$(25\%)\left(\frac{240\ \text{towers}}{1\ \text{tower/crew/day}}\right)\left(\frac{12\ \text{men}}{\text{crew}}\right)\left(\frac{10\ \text{hrs}}{\text{man/day}}\right)\left(\frac{\$28}{\text{hr}}\right) = \$201{,}600$$

Savings because the crane and crane operator are not required to set the towers are:

$$(8\ \text{months})\left(\frac{160\ \text{hrs}}{\text{month}}\right)\left(\frac{\$18 + 67}{\text{hr}}\right) = \$108{,}000 \ .$$

Again, the HLA with a useful load of 45,372 kg (50 tons) is considered using the hourly TOC's of the previous case study. The HLA will be required a maximum of 60 hours to support the erection phase. The total HLA costs are:

$$\text{Lift mode: } (60\ \text{hrs})\left(\frac{\$2147}{\text{hr}}\right)\left(\frac{1.25\ \text{RP}}{\text{TOC}}\right) = \$161{,}025$$

Ferry mode: (See previous study) = $ 33,547

Again, the project can be completed more quickly with the HLA. Under good terrain conditions the line could probably be constructed within one year. The HLA will permit the line to be completed within nine months due to erecting the complete towers as a unit more quickly than the piece-by-piece technique currently used. Based upon the above net savings and the requction in project span time from 12 to 9 months and an interest rate of 1%/month, the estimated investment savings is $99,811.

c) HLA Cost Benefit Summary

1) HLA Costs = -$194,572
2) Crane Cost Savings = + 108,800
3) Erection Cost Savings = + 201,600
4) Investment Cost Savings = + 99,811
5) Cost Savings Summary = + 215,639

4.4.4 Mining Industry

Airship applications that appeared promising in the mining industry that were considered in detail during the study included:

1) The transport of operating personnel to and from mine sites by small non-rigid airships;
2) The transport of concentrate from the mine sites by large rigid airships; and,
3) The use of the HLA in the construction of mine sites.

This latter application is not documented herein because of similarity to HLA case studies previously documented. The remaining two applications are discussed below.

4.4.4.1 Transport of Mine Operating Personnel - 60 km(32 nm) trip

a) Primary Benefit

Reduced cost to mine operators in comparison to the existing helicopter service.

b) Mine in the study area are typically displaced from viable population centers. In order to avoid ghost towns after a mine becomes non-productive, provincial Governments are discouraging the building of a town at mine sites. Thus, the operator is faced with transporting the people to the mine site. More and more, for a variety of reasons such as circuitous routing of highways, paid travel time and distance of travel, etc. air transport is being used and/or considered.

This case study establishes the cost benefit that a small modern conventional non-rigid airship (ZPG-X-5K) provides over a currently contracted for helicopter service in moving mine personnel a one-way distance of 60 km (32 miles). Also presented are comparative estimates for a Twin Otter (DHC-6 and DHC-7). Two hundred twenty-four (224) people are transported to and from the mine site each day by helicopter.

The current contract price for the S-61 helicopter that is being used is \$0.18/ASkm (\$0.33/ASnm). Table IX indicates the

Table IX. COMPARISON OF S-61 CONTRACT PRICE WITH TWIN OTTER, DHC-7, AND ZPG-X-5K AT 60 km

	S-61 Helicopter	Twin Otter	DHC-7	ZPG-X-5K Airship
Passenger Seats	32	19	54	74
DOC/ASkm	0.102	0.11	0.12	0.03
IOC/ASkm (Considered at 50% of DOC for all Aircraft	0.051	0.055	0.055	0.015
TOC (IOC + DOC)	0.153	0.163	0.175	0.045
Tariff[1]	0.176	0.19	0.20	0.056
Additional Costs[2]	N/A	0.05	0.05	N/A
Total Expense to Operator/ASNM	0.18	0.24	0.25	0.06

[1] Note all tariffs are 1.15 TOC except airship is 1.25 TOC

[2] Fixed and operating costs for Cat II Fixed Wing Operation

approximate makeup of the S-61 contract price (tariff) along with an estimate of the comparable costs for the airship and the DHC-6 and DHC-7 aircraft and the ZPG-X-5K airship for the same application. Note that the total fixed wing aircraft includes a cost to the operator not found in the helicopter and airship. This is the additional facilities fixed and operating expense that these vehicles necessitate. The data for the ZPG-X-5K is based upon an operational altitude of 1524 m (5,000 ft) and the ship is configured with a maximum operational altitude limit of 3,048 m (10,000 ft) under standard day conditions.

c) ZPG-X-5K Cost Benefit Summary

1) ZPG-X-5K Annual Costs:

$$\left(\frac{365\ \text{days}}{\text{year}}\right)(224\ \text{passengers})\left(\frac{2\ \text{trips}}{\text{day}}\right)\left(\frac{59\ \text{km}}{\text{trip}}\right) \times$$

$$\left(\frac{\$.06}{\text{pass. km}}\right)(1.02) = \$590{,}439/\text{year}$$

2) Annual helicopter costs:

$$\left(\frac{365\ \text{days}}{\text{year}}\right)(224\ \text{passengers})\left(\frac{2\ \text{trips}}{\text{day}}\right)\left(\frac{59\ \text{km}}{\text{trip}}\right) \times$$

$$\left(\frac{\$.18}{\text{pass. km}}\right) = \$1{,}736{,}586$$

3) Cost savings/year: $1,736,586 - $590,439 = $1,146,147

4) Cost savings/life of mine (15 years):

15 ($1,146,147)=$17,192,205

Of course, the airship offers a considerably larger advantabe over the Twin Otter and the DHC-7 for the 59 km (32 nm) stage length as is obvious by inspection of Table IX.

4.4.4.2 Transport of Mine Operating Personnel - 278 km (150 nm) Trip

The benefit of the airship in the above case study involving a short trip is obvious. As the trip distance becomes larger, the faster speed of fixed wing aircraft, such as the DHC-7, will eventually lead to its becoming the preferred approach. The distance at which that occurs is on the order of 278 km (150 nm) as indicated by the results of this case study. This case study is purely hypothetical and is constrained to considering the transport of 54 people per trip. The DHC-7 can only carry 54 people whereas the airship could carry 61 people over this trip distance. Therefore, the airshop is considered to be operating at an 89% load factor and the DHC-7 at 100%. It should be noted that the helicopter cannot operate with any appreciable payload at the 278 (150 nm) range.

The following parameters were considered:

3 shifts/day, i.e., 6 trips each 278 km (150 nm) 365 days/yr

DHC-7: Cost to owner = \$0.11/ASkm

ZPG-X-5K: Cost to owner = \$0.08/ASkm

The airship requires approximately 112 minutes to make the trip whereas the DHC-7 requires only 52 minutes. Assuming that only 1/2 hour of travel time per trip would be non-paid, the cost of the airship service must account for paying the workers 1/2 hour per trip beyond what they would be paid if the DHC-7 aircraft were used. At \$10/hr, this amounts, on an annual basis, to:

$$\left(\frac{365\text{ days}}{\text{year}}\right)(162\text{ passengers})\left(\frac{2\text{ trips}}{\text{day}}\right)\left(\frac{0.5\text{ hr}}{\text{trip}}\right)\left(\frac{\$10}{\text{hr}}\right) = \$591{,}300$$

It is estimated that since the airship can land directly at the mine site that it can save 15 minutes per worker per day in comparison to a fixed wing aircraft which must land at an airport. From the airport the workers must be transported overland to the mine site. The estimated annual savings attributal to the airship in that respect is:

$$\left(\frac{15\text{ min}}{60\text{ min/hr}}\right)\left(\frac{\$10}{\text{hr}}\right)\left(\frac{162\text{ workers}}{\text{day}}\right)\left(\frac{365\text{ days}}{\text{year}}\right) = \$147{,}825$$

ZPG-X-5K Cost Benefit Study

1) ZPG-X-5K costs/year:

$$\left(\frac{365\text{ days}}{\text{year}}\right)\left(\frac{162\text{ passengers}}{\text{day}}\right)\left(\frac{2\text{ trips}}{\text{day}}\right)\left(\frac{278\text{ km}}{\text{trip}}\right) \times$$

$$\left(\frac{\$.08}{\text{passenger km}}\right)(1.02) \qquad = \$2{,}682{,}704$$

2) DHC-7 costs/year:

$$\left(\frac{365\text{ days}}{\text{year}}\right)\left(\frac{162\text{ passengers}}{\text{day}}\right)\left(\frac{2\text{ trips}}{\text{day}}\right)\left(\frac{278\text{ km}}{\text{trip}}\right) \times$$

$$\left(\frac{\$.11}{\text{passenger km}}\right) \qquad = \$3{,}616{,}391$$

3) Cost of lost time due to airship speed = $1,182,600
4) Cost savings due to airship landing at mine = $ 147,825
5) Cost savings = $3,616,391 + $147,825 - ($591,300 + $2,682,704) = $490,212

Thus a cost savings is indicated even for a trip distance of 278 km (150 nm). It is not clear, however, that the airship would be used for this length trip simply because of the extra time. It is also possible to consider somewhat higher airship speeds and this would certainly be done prior to any decision to pursue development of a passenger carrying vehicle. Reference 22 documents a Goodyear study recently completed for NASA that considers a higher design speed.

The above case studies also suggest that under the appropriate conditions, e.g., shuttle from Vancouver to Victoria, that the airship can expect to compete in a commercial situation.

4.4.4.3 Transport of Concentrate From Remote Mine Sites

A reasonably thorough investigation of transporting concentrate from Northern mines was completed. Large rigid airships 0.85×10^6 m^3 (30×10^6 ft^3) and larger appear marginally better than any other existing air mode. However, all air modes appear to lead to transportation costs that render the market price of the concentrate non-competitive.

4.4.5 Forest Industry

There appears to be two significant applications for the heavy lift airship in the forest industry. The initial application discussed below relates to fire fighting and the second relates to logging. There are two fire fighting applications (chemical treatment and movement of heavy equipment to create fire breaks) that appear promising. However, at present there is only sufficient data to permit a case study of the benefit of moving heavy equipment to create fire breaks.

4.4.5.1 Movement of Heavy Equipment to Create Fire Breaks

a) Primary Benefit

Savings in timber resources by being able to move heavy equipment to create fire breaks independent of terrain conditions.

b) Discussion of Application and Relevant Data

During the forest fire season, the soil conditions in Alberta can often prevent the movement of heavy equipment (bulldozers) needed to create fire breaks. During the spring of the year high water can also present problems in moving in equipment. On occasions, 8,094 to 12,141 ha (20,000 to 30,000 acres) of timber can be lost. Two cases are considered below in terms of the cost benefit of the HLA in preventing timber losses. Case I considers a situation where 4,047 ha (10,000 acres) are saved and Case II a situation where only 405 ha (1,000 acres) are saved. Based upon conversations with knowledgeable personnel in the Alberta forest industry, prevention of the loss of these acreages is very plausible by being able to move the equipment when needed.

The Government places a range of values on their forest land. For purposes of this case study a representative of value of $324/ha ($4,800/acre) has been considered.

It appears that at a maximum six pieces of equipment would have to be moved by the HLA a distance of 16 km (10 miles) or less. It is anticipated that the equipment can be moved in three hours of operation. An HLA with a useful load of 45,372 kg (50 tons) has been considered since the weight of the bulldozers are in the 36,298 kg (40 ton) range. From

Section 4.2.3.1, the hourly TOC for the HLA is $2,147.

c) Cost Benefit Summary

1) HLA Costs:

Lift Mode $= (3\ \text{hr})\left(\frac{\$2147}{\text{hr}}\right)\left(\frac{1.25\ \text{RP}}{\text{TOC}}\right) = \$\ 8{,}051$

Ferry Mode $= \left(\frac{1851\ \text{km}}{148\ \text{km/hr}}\right)\left(\frac{\$2147}{\text{hr}}\right)\left(\frac{1.25\ \text{RP}}{\text{TOC}}\right) = \$\ 33{,}547$

2) Value of Timber Saved:

Case I =($1977/ha)(4,405 ha) = $8,000,000

Case II =($1977/ha)(440 ha) = 800,000

3) Cost Savings:

Case I = $8,000,000 - (8,051 + 33,547) = $7,958,402

Case II = $ 800,000 - (8,051 + 33,547) = 758,402

4.4.5.2 Logging

a) Primary Benefit

Reduced costs of current helicopter logging operations.

b) Discussion of Problem and Relevant Data

Forestry has come a long way from the time when easily accessible areas were cleared down to the stump and the logs transported out by the cheapest method available without regard to reforestation, spill custivation and environmental considerations. Currently, forestry is both an art and a science using modern agricultrual and engineering methods to cultivate the land and to harvest the timber. It is recognized that the variables in modern forestry and logging practices are many. This case study will attempt to highlight some of the harvesting methods currently used under conditions that exist in the Pacific Northwest region of the United States and Canada.

(1) Definition of Logging Functions

The total process of logging or harvesting of timber consists of a number of interrelated functions and subfunctions. Each of these functions is described below.[1]

1. Felling

   Felling describes the process of cutting down the the tree. In most cases this is accomplished with power saws or other mechanical equipment.

2. Bucking

   Bucking is the process used to cut a felled tree into segments. The segments of the tree after it has been bucked are called bolts or logs. If only the top of the tree is removed, it is called a tree-length log.

3. Measuring

   Prior to bucking, the tree is measured to insure proper length of the logs. The length is dependent upon the final use of the log and can vary from bolts of 2.54 m (100 in.) to logs in excess of 15.25 m (50 ft) in length

4. Skidding or Yarding

   Once the trees have been bucked they have to be hauled to a landing area for further transportation to a lumber mill or pulp plant. This primary transportation from the stump to the landing area is called skidding. When cables, helicopters or other aerial systems are used, the skidding process is often referred to as yarding.

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[1] All definitions are based on Steve Conway, "Logging Practices. Principle Timber Harvesting Systems" (Miller Freeman Publications, Inc.), 1976, pp. 50-54.

5. Loading

Loading refers to the placing of the logs or bolts on a haul vehicle at the landing area to further transportation to a transfer point for reloading onto another mode of transportation or directly to the lumber mill or pulp plant. The loading at the landing area and the transfer points is normally accomplished with mechanized equipment.

(2) Variables Affecting Logging Operations

There are numerous variables that affect the logging operations. Some of the major variables affect the selection of skidding and yarding methods.[2]

1. Volume Per Hectare

Volume per hectare refers to the density of trees per hectare. This variable will have great influence on the overall cost on logging a tract, because there is an inverse relationship between the volume per hectare and the logging costs. The volume per hectare variable will affect the cost of the operation with minimal regard to the method of logging used.

The definition of high and low volumes per hectare are highly dependent upon the type of cut (clear cut, partial cut or salvage cut), the logging system utilized and the geographic location of the cut. In the Pacific Northwest a volume of 174.87 to 204.02 m^3/-hectare (30,000 to 35,000 board feet per acre) is considered a good volume for an area to be clear cut. A company operating in the southern states of the U.S. considers 4.66 to 5.83 m^3/hectare (800 to 1,000 board feet per acre) a sufficient volume to start operation on selective cutting. A comparable company in the Pacific Northwest on the other hand would be reluctant to start a selective cutting operation with a volume of 46.63 to 58.29 m^3/hectare (8,000 to 10,000 board feet/acre).

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[2] Ibid, pp. 67-78

2. Volume per Stem

   This variable is closely related to the volume per acre. Volume per stem refers to the volume per tree in an area. Generally the logging cost increases with decreasing tree size, because more trees will have to be handled per unit of output. This variable will also affect the selection of equipment for the operation.

3. Defect

   Defect refers to the difference between the gross and the net scale or cubic measurement of the log. Loggers are always paid on a net scale which is the gross scale or measurement of the log with deductions made for defects in the logs. Defects may be caused by the felling, skidding or transportation. The cost of operation per unit will be seriously affected with large amounts of defect in the timber.

4. Topography or Terrain

   The topography or terrain will, to a large extent, determine the type of logging methods that can be applied and also the extent to which logging can be performed, if at all. This will be both a matter of economic and technical feasibility of the various available methods. In steep grades the efficiency of conventional skidding systems become low.
   In many cases conventional skidding is completely

impossible, and higher cost cable systems may have to be employed.

5. Environmental Variables

Environmental variables refer both to the soil and the weather conditions in an area and both have an impact on the logging methods that are to be employed. Environmental concerns regarding the soil conditions and the possibility of reforestation of an area may preclude the use of certain equipment. An example is logging in the Alaskan muskey areas. Tracked machines and skidders cannot be used under these circumstances, and logging roads have to be carefully constructed. Alaskan loggers have used both cable systems and helicopters for yarding of the felled logs.

Similarly weather can seriously affect the logging operations. Wind, snow, rain, and humidity may slow the operation considerably in some regions. In nothern Canada, for example, the hauling of logs is limited to 110 days per year during the winter season, when the ground is solidly frozen.

6. Weight of Logs

A major variable in selecting a skidding or yarding system is its capacity to carry the logs. Although most logs are measured in terms of their cubic measurement, weight is the important factor in the skidding or yarding operation. Table X presents the weight per cubic metre of some commercial species of lumber.

TABLE X. WEIGHT PER CUBIC METRE OF SELECTED COMMERCIAL SPECIES

Species	kg/m^3	Species	kg/m^3
Red alder	742	Western larch	774
Yellow birch	935	Red oak	1016
Alaska cedar	581	White oak	1000
Western red cedar	435	Longleaf, shortleaf and slash pine	1000
Douglas fir (coastal)	613	Loblolly pine	1000
Noble fir	484	Lodgepole pine	629
Red fir	774	Ponderosa pine	726
White fir	758	Western white pine	564
Black gum	726	Yellow poplar	613
Red gum	806	Black spruce	516
Eastern hemlock	806	Sitka spruce	532
Western hemlock	661	Sweetgum	806
Hickory	1016	Black walnut	935

The current case study considers the airship in competition with the helicopter (S-64E) in one of the above described logging operations (i.e., yarding). Typically, the helicopter is only used to yard the logs and thus the helicopter costs do not represent the entire cost of the logging operation. It is shown below, however, that the costs of yarding with the HLA are so much lower than that of the helicopter that the HLA con be expected to have a much larger market in the logging industry than current helicopter operations.

It should be noted that the size of HLA that is well suited to a yarding operation will be a function of the size and density of the trees being cut. This case study examines an HLA with a 45,372 kg (50 ton) useful load capability which provides a payload capability of 38,112 kg (42 tons) with four hours of endurance. Allowing for a 75% load factor, this results in essentially 28,131 kg (31 tons) of logs. Two medium size Douglas fir trees can weigh this much. Thus, this size HLA does not seem excessively large for the Northwest portions of the U.S.

In structuring the operational base locations of Figure 10, it was contemplated that HLA's based in southern Alberta could serve the lumber industry in the Northwest U.S. The machines would be temporarily based (from an expeditionary mast) near the yarding area during the logging season.

It should be noted that it is not necessarily clear that logging in Alberta with the HLA is practical based upon the size and density of the trees. Logging in British Columbia may be a practical consideration, although 27,223 kg (30 tons) of payload may be excessive. The Aerocrane, which is a leavy lift device under evaluation in recent years that also combines buoyant and rotor lift, also appears potentially suited to logging in British Columbia as well as areas where helicopters are currently being used. It would appear that its slow forward speed capabilities would not penalize it in this application as long as the ambient winds were not excessive. During Goodyear's survey of various logging industry organizations in British Columbia, a comment was made that reforestation was making it unnecessary and uneconomical to consider harvesting trees in areas difficult to harvest. It is these areas where aerial systems typically are of most value. This comment needs further exploration before the true potential of logging in British Columbia can be established.

It is clear that substantial changes in current helicopter logging practices would be required to achieve maximum efficiences with either heavy lift system. Whether either vehicle can significantly cut into the market occupied by conventional logging systems and exactly what range of lift capacity is needed requires further evaluation.

This case study considers the yarding of medium sized Douglas fir logs with a density of 806 kg/m^3 (50 lbs/ft^3). The tree length log is 37 m (122 ft) long and weighs 12,704 kg (14 tons). The tree length logs must be bucked such that it can be yarded by the helicopter. Two tree length logs must be chocked for yarding by the HLA. Both helicopter and HLA are operating at approximately 70% of their nominal payload capability in this situation. The yarding distance is 1-1/4 km (3/4 miles), and an annual utilization of 2,000 hours.

Based on data from the helicopter manufacturer, the yarding cost based upon demonstrated productivity, is $487 for this situation allowing for an inflation factor of 6%/year in the manufacturer's data. The helicopter, to achieve this yarding cost, is flying 19 turns (cycles) per hour. It is anticipated based upon computer simulation of the HLA flying this mission that it can fly at least 10 turns/hour.

The HLA costs are $2147/hr.

c) HLA Cost Benefit Summary

1) HLA Cost

$$\left(\frac{10\ \text{turns}}{\text{hr}}\right)\left(\frac{\text{hr}}{\$2147}\right)\left(\frac{25408\ \text{kg}}{\text{turn}}\right)\left(\frac{\text{m}^3}{801\ \text{kg}}\right) =$$

$0.148\ \text{m}^3/\$$ or $\$6.77/\text{m}^3$

2) S64-E Helicopter costs are $\$20.64/\text{m}^3$

Thus, the HLA is approximately 1/3 the cost of the S64-E helicopter. It may well be appropriate to consider the HLA operating at 100% capacity because of its substantial power margin. In that case, the cost is $\$4.51/\text{m}^3$ or approximately 1/5 that of the helicopter.

It appears, based upon available data for more conventional logging systems, that the HLA system may be able to cut substantially into this market. This point is still under investigation as sufficient data are not really available to characterize the exact cost of competitive systems and the complete description of how an HLA system could be most effectively used.

4.4.6 Transport of Prefabricated Structures

a) Primary Benefit

Reduced transport costs compared to current alternatives.

b) Discussion of application and Relevant Data

The general transport of prefabricated structures (basically remote camp structures) appears to be a large market area for the rigid airship. Figure 30 compares the cost of moving 300 structures 402 km (250 miles) through the bush by various modes. The air modes reflect project investment cost savings where applicable and savings by the installation crew at the

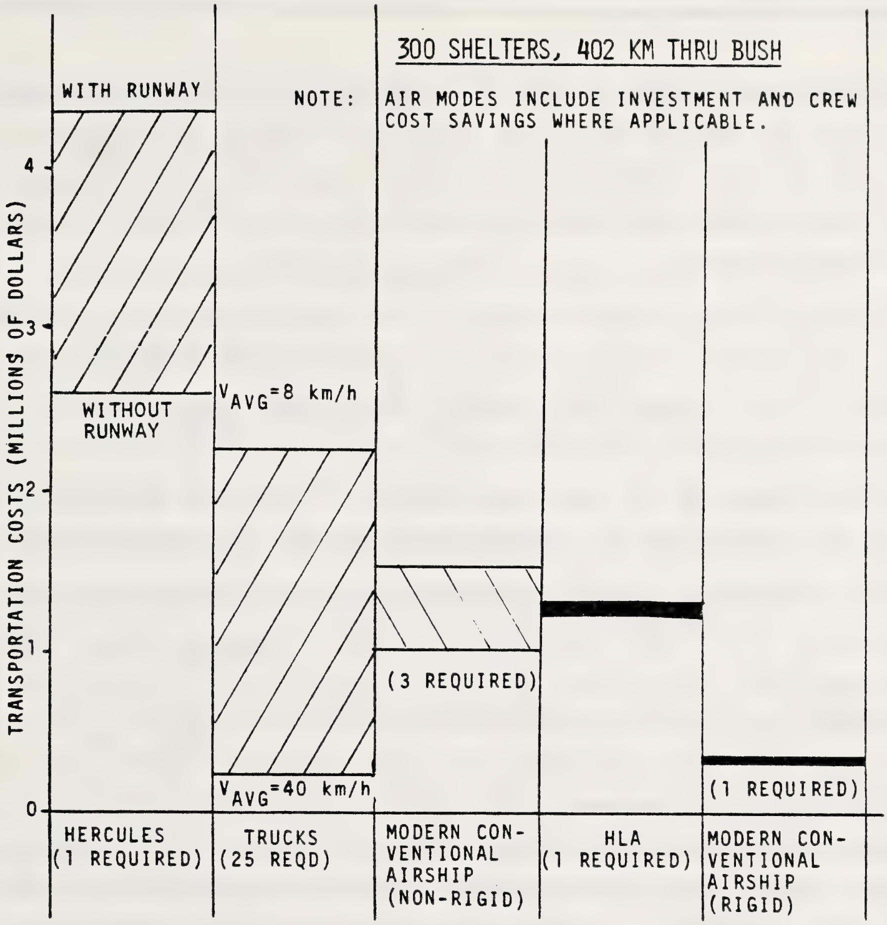

Figure 30 - Transportation Cost Comparisons

remote site. These site installation savings result from the fact that the air modes can reduce the time required to set up a camp because they can get the camp structures there in a shorter period. This is particularly true when the speed of the truck is limited over bush roads.

The Hercules aircraft costs of Figure 30 are presented as band data to represent the cost with and without a runway. Runway costs are for gravel construction which is typical of runways for the Hercules.

Truck speeds ranging from 8 to 40 km/h (5 to 25 mph) are considered in Figure 30 which greatly affects the competitiveness of the truck. Twenty-five trucks have been considered which is typical of the number of vehicles that would be available for such a move.

The non-rigid airship data is for the ZPG-3W configuration. The HLA data is based upon a configuration with a useful load of 90,744 kg (100 tons). The rigid data is for the configuration with a volume of 3.1×10^5 m^3 (11×10^6 cu ft).

Another example of the cost benefit that the HLA could provide in this area is illustrated in the following case study.

ATCO Structures, Ltd., recently transported 44 structures a distance of 90 km (56 miles) across a frozen lake. They shipped the structures several months early during the winter because this was the most attractive alternative. The cost of this move was $110,000 for the transport phase and approximately $90,000 for the installation. ATCO estimates that if they could have moved the structures during the spring or summer that the installation costs would have been reduced by 50%.

An HLA with a useful load of 90,744 kg (100 tons) is considered for this application. Based upon an average structure weight of 12,704 kg (14 tons), the HLA can transport six structures per trip. It is estimated that the HLA will require 1.5 hours per round trip or 11 hours of operation to move the structures. The hourly TOC for the HLA is $3834.

Investment cost savings that occur by using the HLA are based on carrying the value of the structures ($30,000/structure) for 3 months at 1.0%/month. This amounts to approximately $26,000.

c) HLA Cost Benefit Summary

1) HLA Costs:

Lift Mode

$$(11\text{ hrs})\left(\frac{\$3834}{\text{hr}}\right)\left(\frac{1.25\text{ RP}}{\text{TOC}}\right) = \$52{,}718$$

Ferry Mode

$$\left(\frac{1851\text{ km}}{148\text{ km/h}}\right)\left(\frac{\$3834}{\text{hr}}\right)\left(\frac{1.25\text{ RP}}{\text{TOC}}\right) = \$59{,}939$$

2) Truck Costs = $110,000

3) Savings in installation costs = $45,000

4) Investment savings by using HLA = $26,000

5) Cost Savings:

$110,000 + $45,000 + $26,000 - (52,718 + 59,939) = $68,343

ATCO recently transported structures by truck over established roads from Calgary to Anchorage at a cost of $3700/structure. The cost of transporting structures by the large rigid airship this distance is on the order of $3500/structure. Both vehicles require a cargo to back haul to achieve these rates. The reason for bringing up this example is to illustrate, in a situation where roads already exist over which trucks can achieve their normal transit speed, that the large rigid airship can compete.

The economic benefits that the airship offers if roads do not exist or existing roads necessitate reduced transit speeds by the truck are somewhat obvious.

ATCO has stated that they are shipping more and more by air (Hercules). Physical constraints of that aircraft limit the number of structures per flight to one. The cost per mile per shelter is then approximately \$6.70 based on recent PWA data. The cost to the shipper for transporting structures by Hercules a distance of 2776 km [1500 NM] is then approximately \$10,000. The cost to the shipper to ship the structures by the large rigid airship considered herein would be on the order of \$4,400.

Thus, it would appear that a large rigid airship could capture the entire Hercules market in this area as well as expand it because of a considerably lower cost/structure.

4.4.7 General Transport

4.4.7.1 General

The purpose of this section of the report is to provide an indication of the conditions under which airships are a more attractive transport mode than currently available modes in the study region. Several comparisons are discussed below that should cover a wide number of shipments to/from the study region.

4.4.7.2 Comparison with Trucks

Published truck rates* as of May, 1978, into the study region would indicate a truck tariff of $\$6.8 \times 10^{-5}$/kg-km [\$0.10/ton-mile] is reasonably representative when considering the transport of a truck-load shipment, e.g., 18,149 kg [20 tons].

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*Provided by Alberta Transportation Ministry

Two cases are considered below. The initial case involves shipment of goods over winter roads with the entire shipment completed in one winter season. The second case involves all-weather roads such as would be required in the case of transporting concentrate from a remote mine site. In both cases truck plus road costs are compared to the airship transport cost. The implication of investment losses is addressed in the case of the shipment of goods over the winter roads. Investment losses occur because goods must be shipped during the winter often several months before they are needed. Inventory costs, in the case of the truck mode, were neglected.

First year construction and maintenance costs for winter roads were considered at \$10,565/km [\$17,000/mile].

All-weather road construction was considered to be a gravel roadway with a 9.14 m [30 ft] top width capable of handling 34,000 kg [75,000 pound] loads. It was assumed that road construction materials would be available within the immediate area and that the terrain was reasonably flat. A per mile cost of \$250,000 was assumed. There were no bridge structures considered.

Figures 31 and 32 present a transport cost comparison between trucks operating over winter roads and the three types of airships examined during this study for transport distances of 161 and 1609 km [100 and 1000 statute miles], respectively. Figures 31 and 32 provide the transport cost comparison as a function of the load transported. The airship is more cost-effective for loads

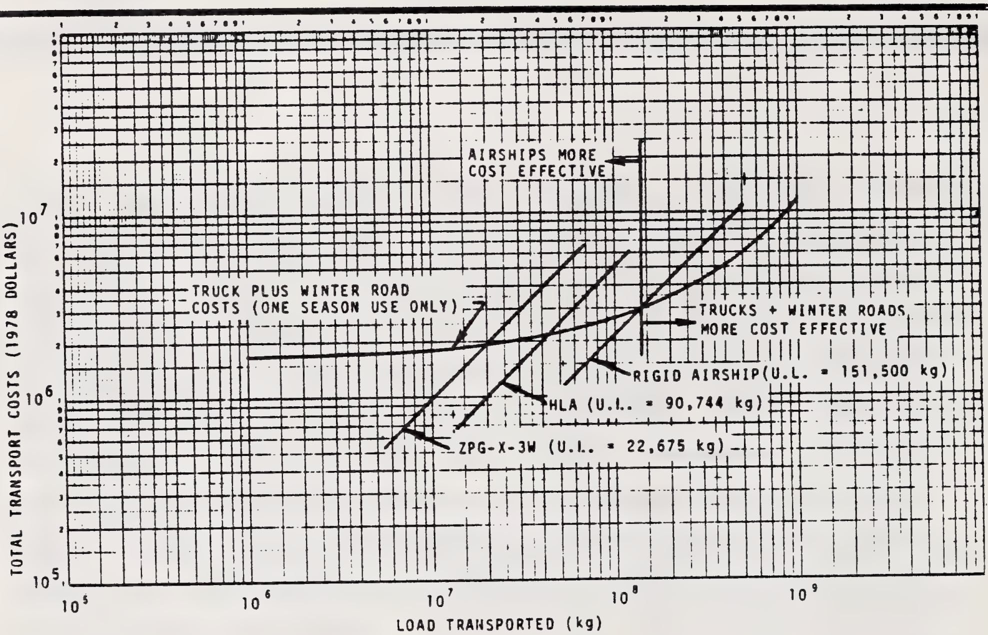


Figure 31 - Truck vs Airship Transport Cost Comparison for Transport Distance of 161 km Considering Winter Road Construction [One Season Use Only - Cargo Transported Both ways]

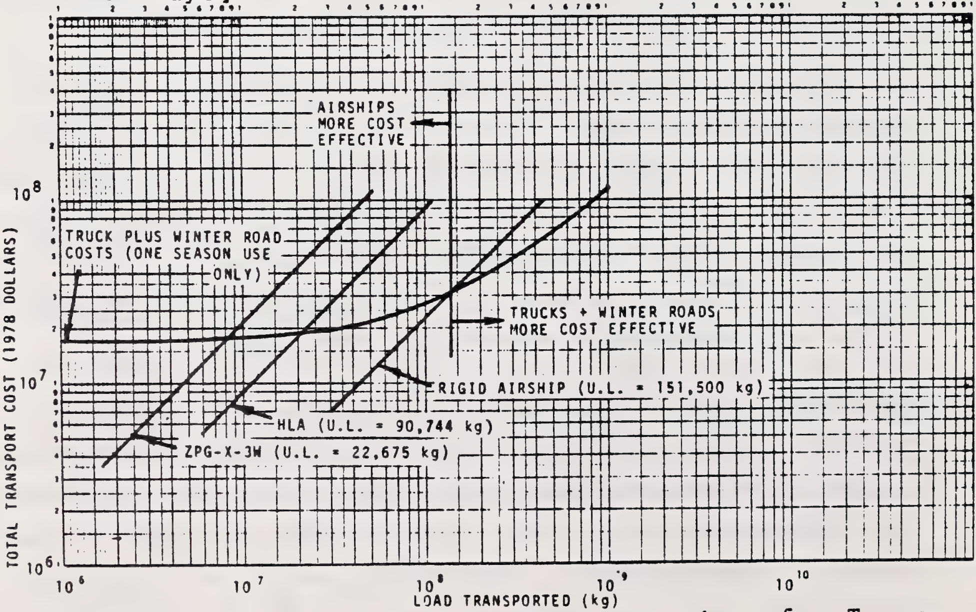


Figure 32 - Truck vs Airship Transport Cost Comparison for Transport Distance of 1609 km Considering Winter Road [One Season Use Only - Cargo Transported Both ways]

less than those represented by the intersection of the curve entitled "road plus truck cost" and the line representing the transport cost for the airship in question. For loads greater than those represented by that intersection, the building of a winter road and transporting by truck is preferrable.

From Figure 31 it can be seen that for a transport distance of 161 km [100 statute miles] and loads up to 1.27×10^8 Kg [140,000 tons] rigid airships are preferrable to trucks. For airships up to 38.1×10^6 kg [42,000 tons] the HLA is more attractive than trucks plus winter roads at the transport distance of 161 km [100 statute miles]. The above represent significant shipments of cargo and suggest a potentially large general transport market for airships.

Another factor that makes the airship potentially more attractive to this market than indicated in Figures 31 and 32 is the fact that the goods can be shipped by airship when they are needed as opposed to several months early during the winter season. Figure 33 illustrates the economic benefit offered by the airship in terms of investment cost savings. Repeated in Figure 33 is the information of Figure 31 on which has been superimposed the investment losses associated with early shipment of goods over winter roads. Shipments must almost always be made two months before they are needed and often times up to six months early. In generating Figure 33, the value of the goods shipped was considered to be $1.00/-

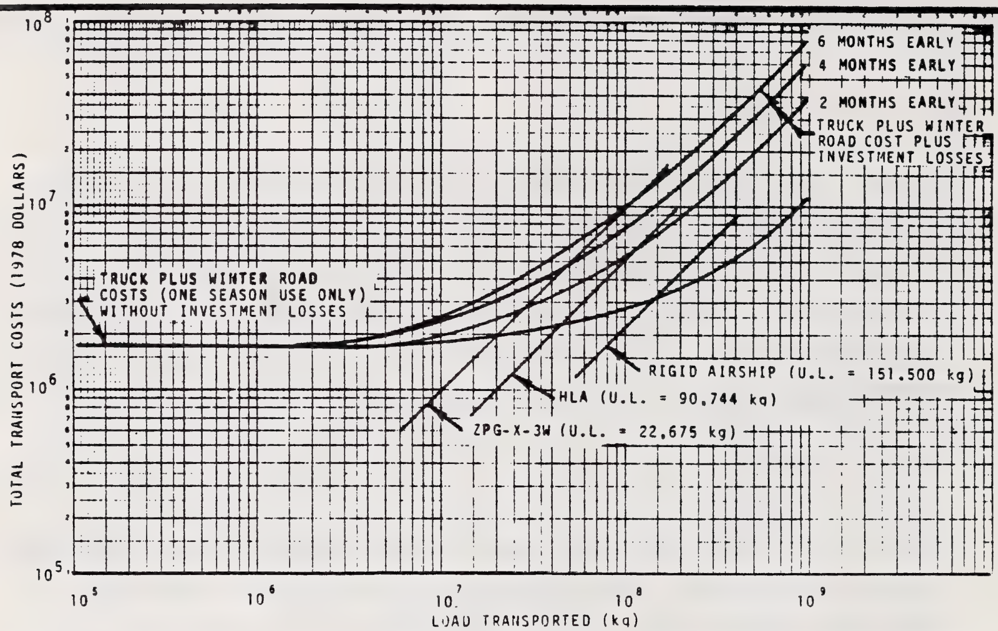


Figure 33 - Truck vs Airship Transport Cost Comparison for Transport Distance of 161 km Considering Winter Road Construction [One Season Use Only] and Investment Losses

pound and an interest rate of 1%/month was used to define the investment losses involved in shipping early.

Consideration of investment losses has the affect of increasing the quantity of goods which the airship can transport more cost-effectively than can trucks over winter roads. Consideration of investment losses would seem to indicate that the rigid airship will always be more cost effective than winter roads for any quantity shipped.

Figures 34 and 35 provide a comparison similar to Figure 31 and 32 except that the comparison involves trucks operating over an all-weather road. This comparison is of significance to a situation such as the transport of concentrate from a remote mine. Dedicated all-weather

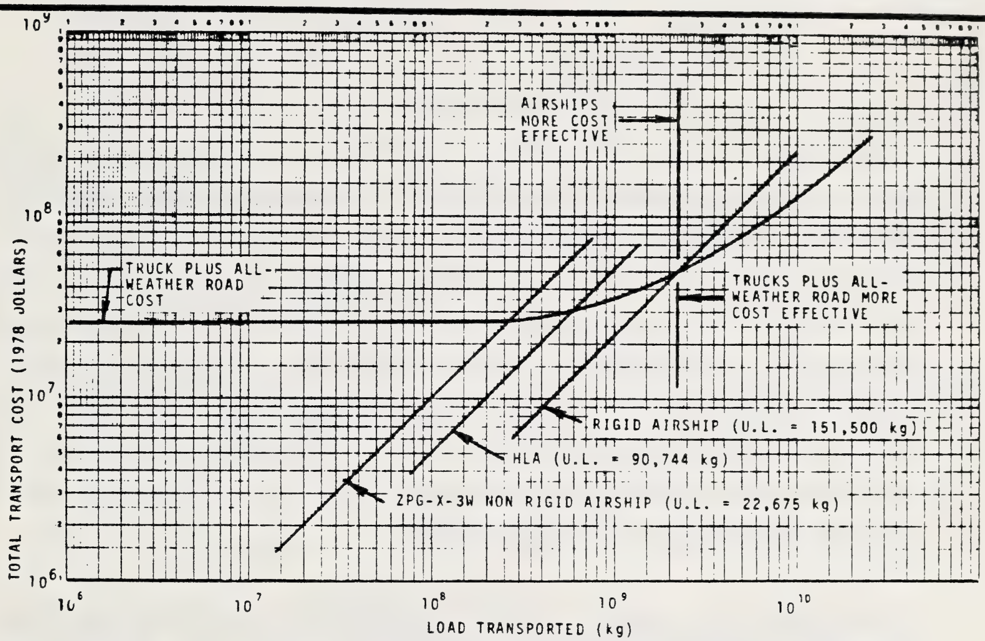


Figure 34 - Truck vs Airship Transport Cost Comparison for Transport Distance of 161 km Considering All-Weather Road Construction - Cargo Transported Both Ways

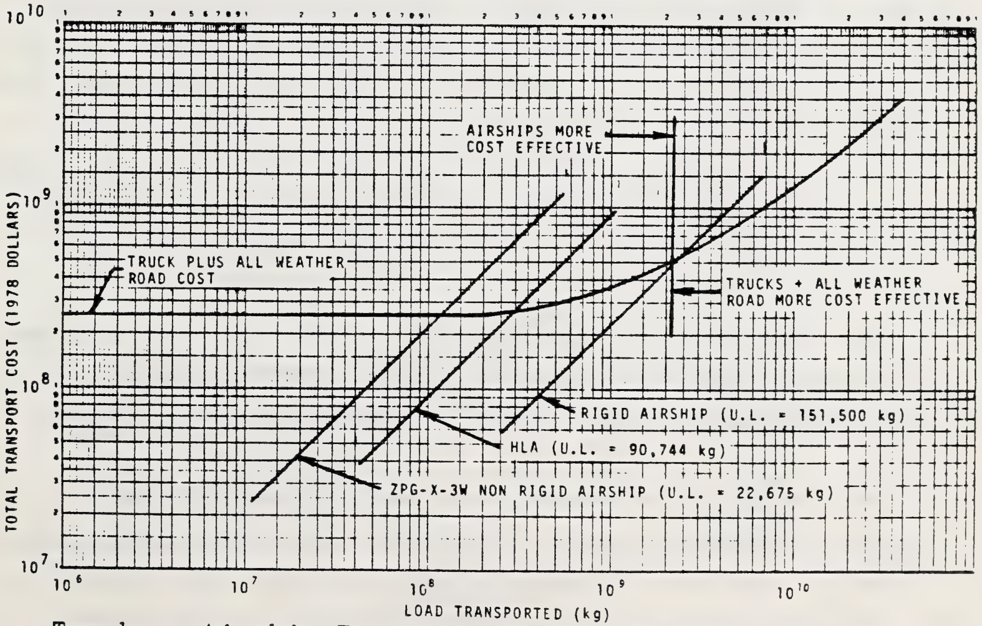


Figure 35 - Truck vs Airship Transport Cost Comparison for Transport Distance of 1609 km Considering All-Weather Road - Cargo Transported Both Ways

roads are currently being considered to transport concentrate from Northern mine sites. A typical mine might produce 453,600 kg [500 tons] of concentrate per day, 365 days per year for 15 years. This results in a total of 2.48×10^9 Kg [2.74×10^6 tons] of concentrate being shipped. From Figures 34 and 35 it can be seen that a rigid airship with a useful load of 151,502 kg [167 tons] is essentially as cost effecitve as trucks operating over all-weather roads. At lesser total load shipped, the rigid airship will be preferred.

Figures 31 through 35 have considered a situation where payload is carried during the backhaul. An empty backhaul has the effect of reducing the total load shipped up to which the airship is the preferred transport mode. This is because the road costs become a lesser percentage of the total transport cost for the "road plus truck mode" when an empty backhaul is considered. Figure 36 illustrates this effect in the case of the rigid airship for both winter and all-weather roads for a transport distance of 1609 km [1000 statute miles].

From Figure 36 it is clear that even when considering an empty backhaul that the rigid airship is the preferrable mode up to rather a significant total load.

Plots similar to those above can be constructed for other transport modes. Figure 37 illustrates a comparison of the total transport cost of the rigid airship,

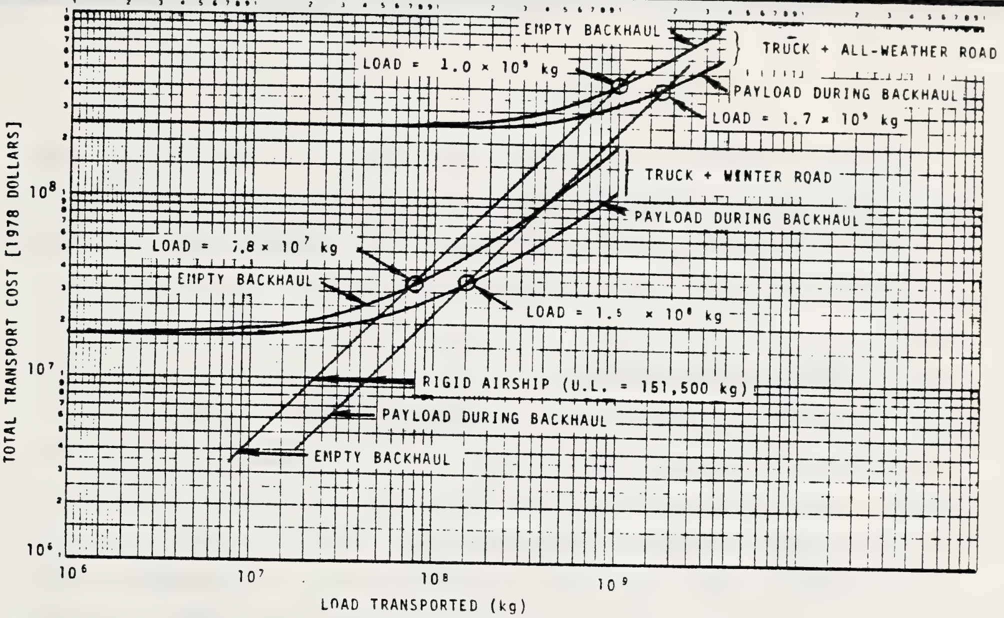


Figure 36 - Effect of Empty Backhaul on Total Transport Cost Comparison of Rigid Airship and Road plus Trucks for Transport Distance of 1609 km

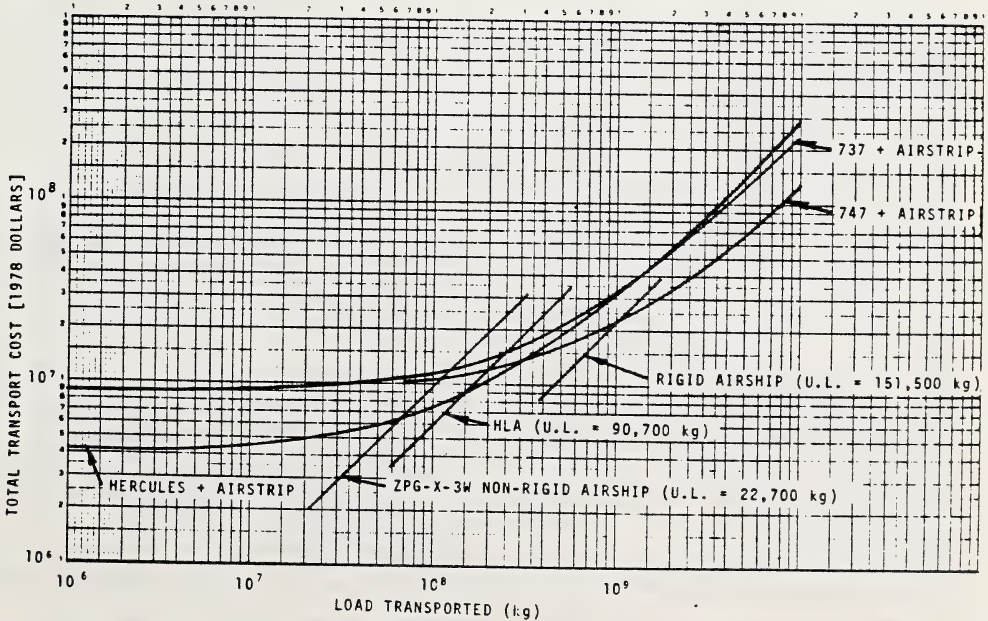


Figure 37 - Comparison of Total Transport Cost for Various Air Modes at 161 km [Cargo Transported Both Ways]

HLA and ZPG-X-3W airship with that of the Boeing 747, 737, and the Lockheed Hercules aircraft. The 747, 737 and Hercules require runways. Airstrip costs were considered based on the following:

Runway Cost Data

1.37 m crushed rock at \$25.51 m^2
Surfacing at \$24.21 m^2
Length = 2743 m [737 and 747]
Length = 1524 m [Hercules]
Width = 45.7 m

Buildings, Lights, Equipment

\$2,500,000

Airstrip costs are:

737/747

[2743] [45.7] [25.51] = \$3,197,809 [gravel]
[2743] [45.7] [24.21] = \$3,038,847 [surface]
\$2,500,000 [building & equipment]
TOTAL \$8,732,656

Hercules*

[1524] [45.7] [25.51] = \$1,776,690 [gravel]
\$2,500,000 [building & equipment]
\$4,276,690

---

*Note that the Hercules does not require a surfaced runway.

An empty back haul may have the effect of reducing the total load at which the airship is the preferred mode dependent upon which airship and which airplane are being compared. This is because the fixed cost [runway, landing equipment, etc.] become a lesser percentage of the total transport cost for the airplane when an empty back haul is considered. Figure 38 illustrates this effect by replotting HLA and 737 data from Figure 37 and including new data to show the impact of an empty back haul. From Figure 38 it can be seen that the empty back haul reduces the total load from 2.27 × 10^8 kg [2.5 × 10^5 tons] to 1.2 × 10^8 kg [1.32 × 10^5 tons] at which the HLA is preferred over the 737 for a 161 km [100 mile] transport distance.

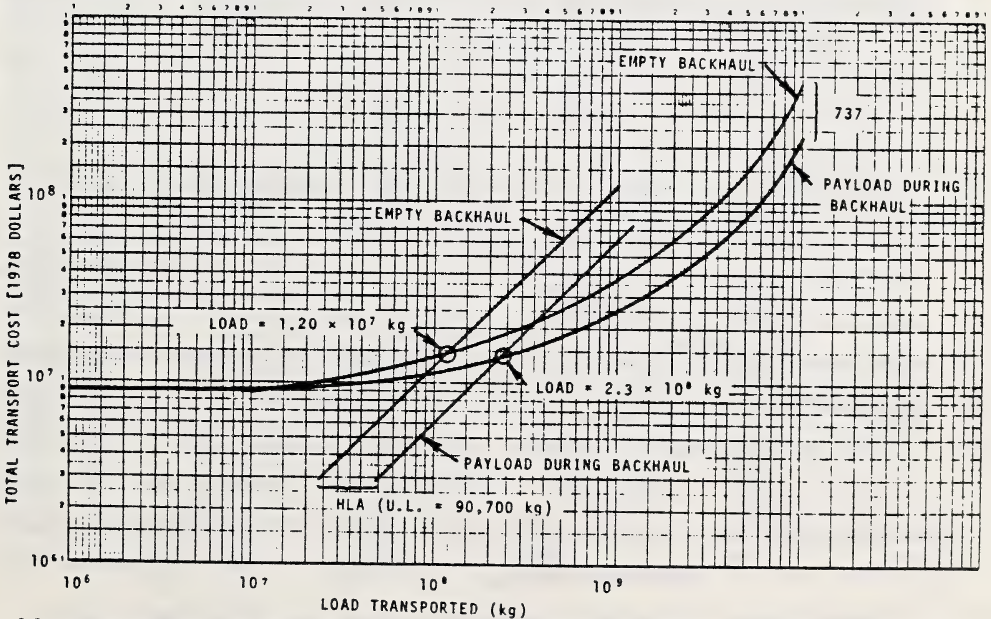


Figure 38 - Effect of Empty Backhaul on Air Mode Comparisons at 161 km

Of course, where the tariff for the airship is less than that for the airplanes [see Figure 25] the airplane is never a more cost effective mode at any total load transported. This is seen in Figure 37 from the fact that the cost curve for the rigid airship never crosses the Hercules or 737 cost curves.

Figure 39 provides a comparison of total transport costs for the various air modes of Figure 37 at 1609 km [1000 statute miles]. Again, an empty backhaul would have the effect of reducing the total load up to which the various airships are the preferred mode. Exceptions to this occur when the rigid airship is compared to the 737 and Hercules for the reason noted above.

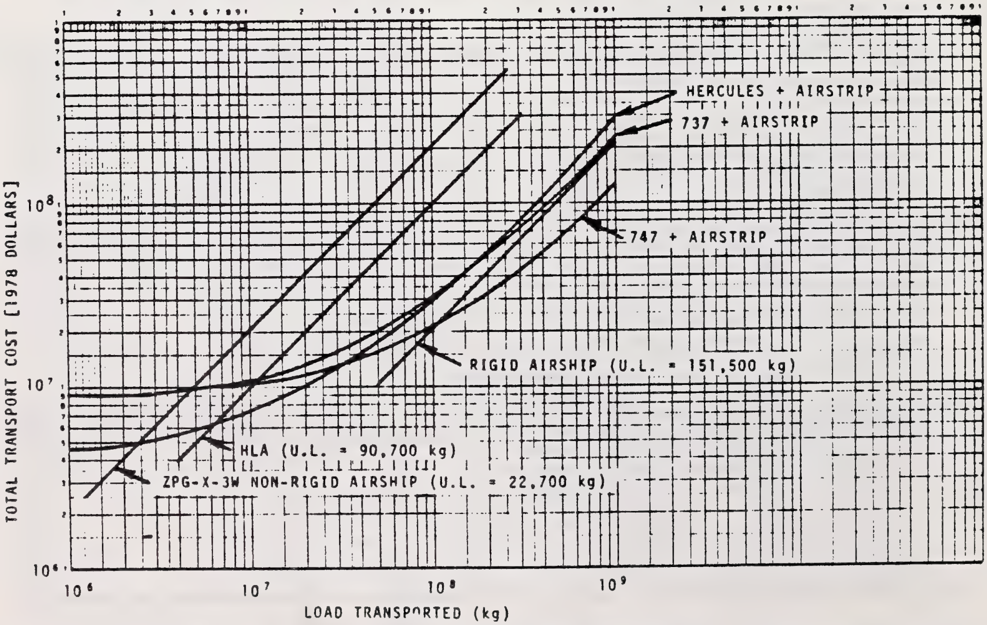


Figure 39 - Comparison of Total Transport Cost at 1609 km [Cargo Transported Both Ways]

From Figure 25 it is obvious that all airship configurations will be preferred in comparison to the shipment of goods by helicopter. This factor is of interest to large remote projects where the use of helicopters is anticipated to move in reasonably large quantities of goods. The Polar Gas Pipeline construction plan currently reflects considerable possible use of both the S-61 and S-64 helicopters in just such a capacity.

4.5 Estimate of Airship Demand

Figure 40 indicates locations within the study area where major projects are planned within the next ten to fifteen years. These projects were identified from reference material [References 1 and 2] relative to the study area. Also included in Figure 40 is the operational base concept for the HLA discussed in Section 3.2. As noted in Figure 40 the 926 km [500 nm] ferry distance considered in the previous case studies includes or nearly includes a substantial portion of projected developments within the study area. Figure 41 indicates a projection based on Reference 2 data relative to expected level of economic activity related to industrial development in the study area. Both Figure 40 and 41 combine to suggest that considerable growth can be expected in the study area. Also noted on Figure 41 is the cost to rent 10 HLA's of a 90,744 kg [100-ton] useful load capacity on a continuous basis over the period of the projection. Thus, it is reasonably clear that the study area is projected to have the economic base necessary to support an airship service.

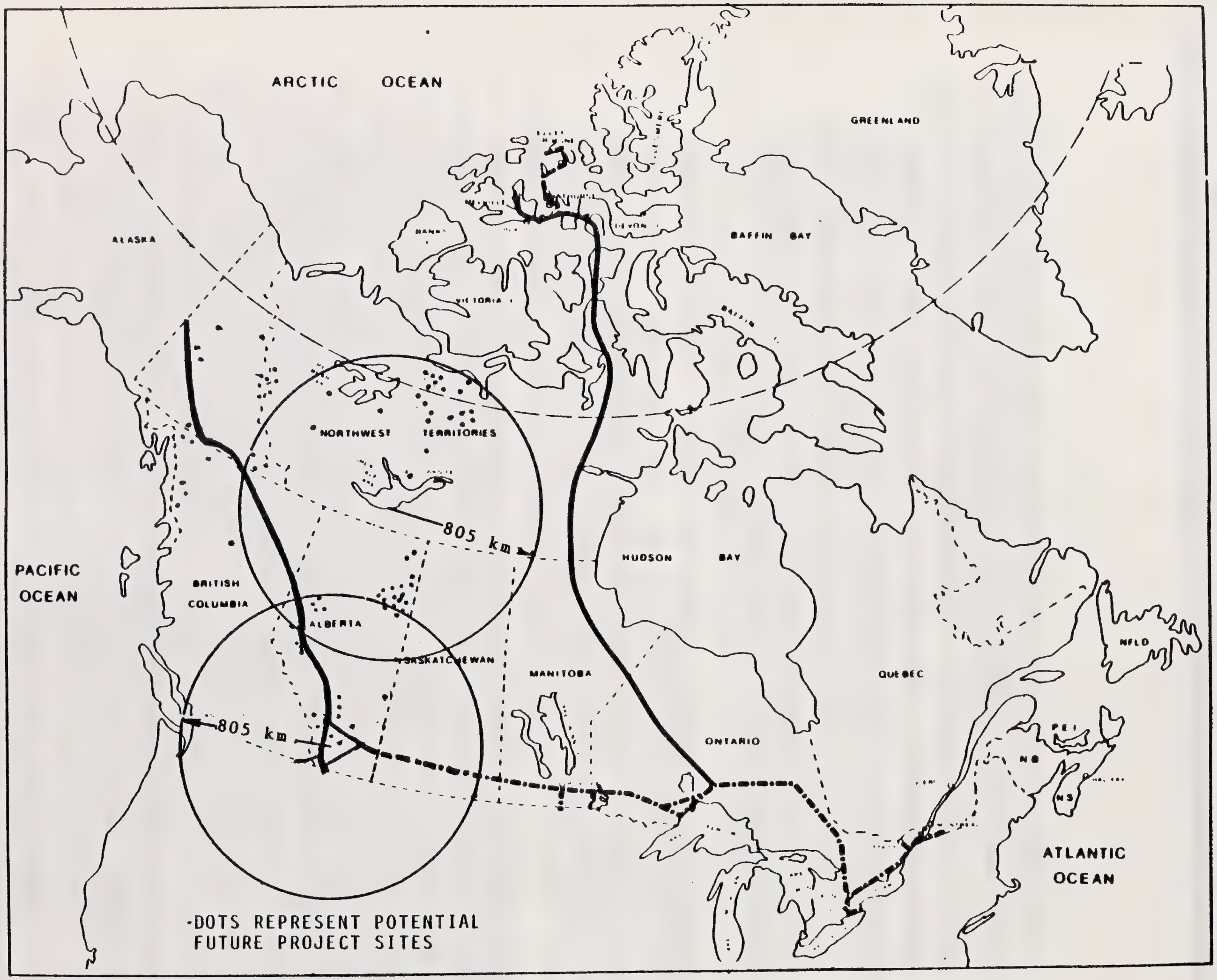
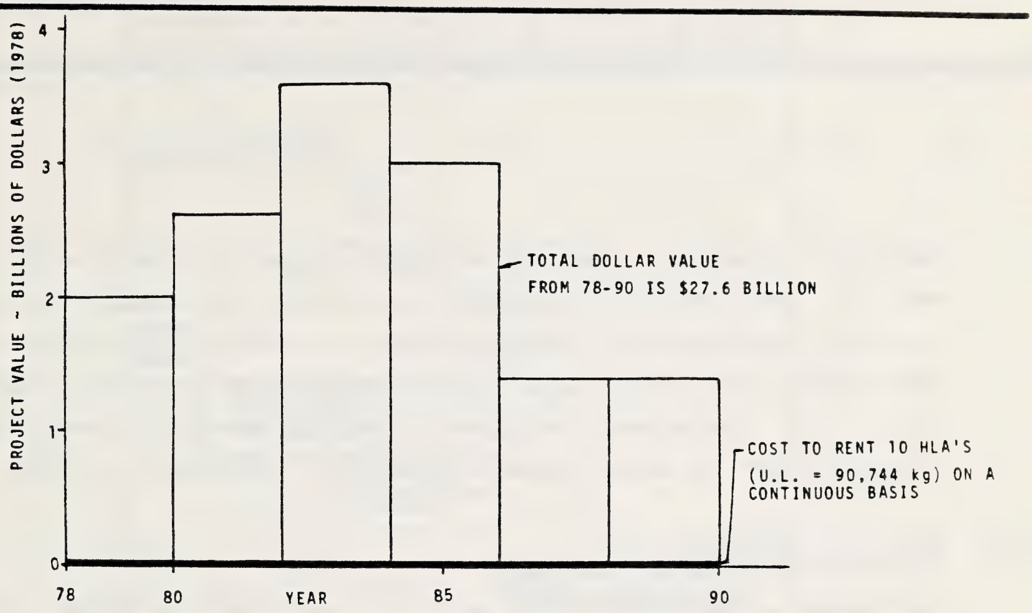


Figure 40 - Canadian Projects With Potential Airship Applications



* FROM REFERENCE 2

Figure 41 - Projected* Construction Costs Of Industrial And Resource Projects Relevant to Northeast Alberta That Would Support HLA Rental Services

TABLE XI - NUMBER OF AIRSHIPS MARKETABLE AND PRINCIPAL USERS

CONFIGURATION	CURRENT DEMAND (NUMBER OF SHIPS)	
	WORLD WIDE	CANADA
HEAVY LIFT	5 (SHIP OFF-LOADING)	-
	25 (REMOTE PROJECT CONSTRUCTION AND MOVEMENT OF HEAVY, OUTSIZED ITEMS)	4
	8 (LOGGING)	2 (LOGGING IN NORTHWEST U.S.)
	5-25 (MILITARY)	-
MODERN CONVENTIONAL (NON-RIGID) ZPG-X-5K (7,260 kg)	100 (COASTAL PATROL)	2
	25 (PEOPLE/CARGO TRANSPORT)	3
	5 (SURVEY/EARTH RESOURCES)	1
	2 (MILITARY TRAINING)	-
ZPG-X-3W (18,149 kg)	10 (MILITARY)	-
	10 (PEOPLE/TRANSPORT)	2
MODERN CONVENTIONAL (RIGID) (151,543 kg)	5-10 (CARGO TRANSPORT) *	2
	10 (MILITARY)	-

NOTE: TWO SIZES APPEAR TO BE REQUIRED. USEFUL LOAD REQUIREMENTS ARE:
(1) 45,372 kg AND
(2) 90,744 - 113,430 kg

*WOULD FOLLOW MILITARY DEVELOPMENT.

Table XI indicates what is believed to be a conservative estimate of the number of airships that could currently be profitably operated on a rental basis on both a world wide basis and within the study area. Studies currently being sponsored by the U.S. Government suggest that the need for heavy lift sirships may be many times the number indicated in Table XI.

4.6 Vehicle Availability

In recent studies for NASA and U.S. military agencies, Goodyear has identified development requirements, schedules, costs, etc for each of the airships considered herein. The development costs have been used in structuring the TOC data presented previously.

4.6.1 Heavy Lift Airship [HLA]

Figure 42 illustrates the phasing of the program outlined at Goodyear leading to production quantities of the HLA. The demonstration program referred to in Figure 42 would combine existing helicopters [see Figure 43] to achieve a demonstration configuration to verify all technical, cost and operational features of the system prior to proceeding into the manufacturing effort of the production configuration.

4.6.2 ZPG-X Modern Conventional Non-Rigid Airship

Both the 5K and 3W versions of the ZPG-X configuration are near term low risk vehicles in which there is considerable worldwide interest. Figure 44 illustrates the phasing

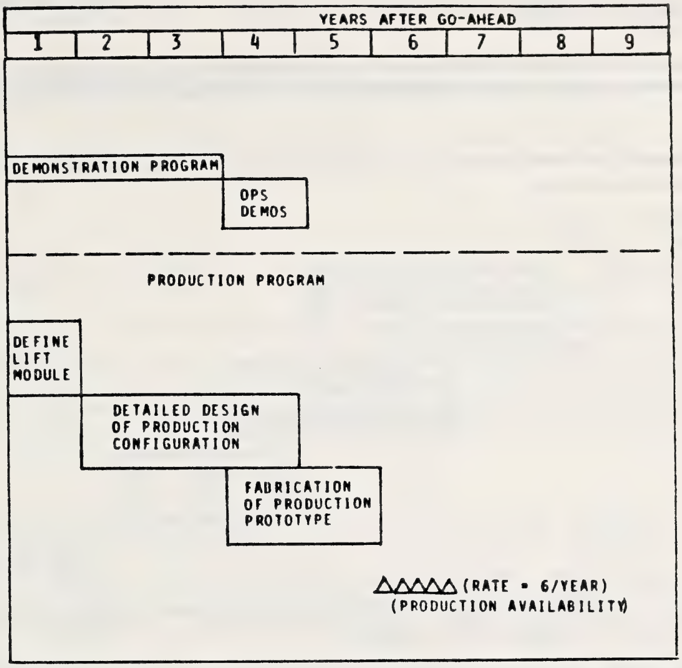


Figure 42 - HLA Production Program Schedule

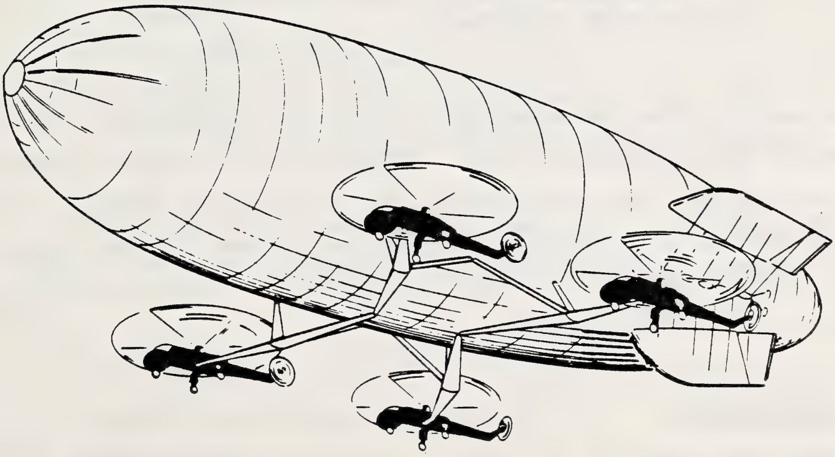


Figure 43 - Illustration of Recommended HLA Demonstration Configuration

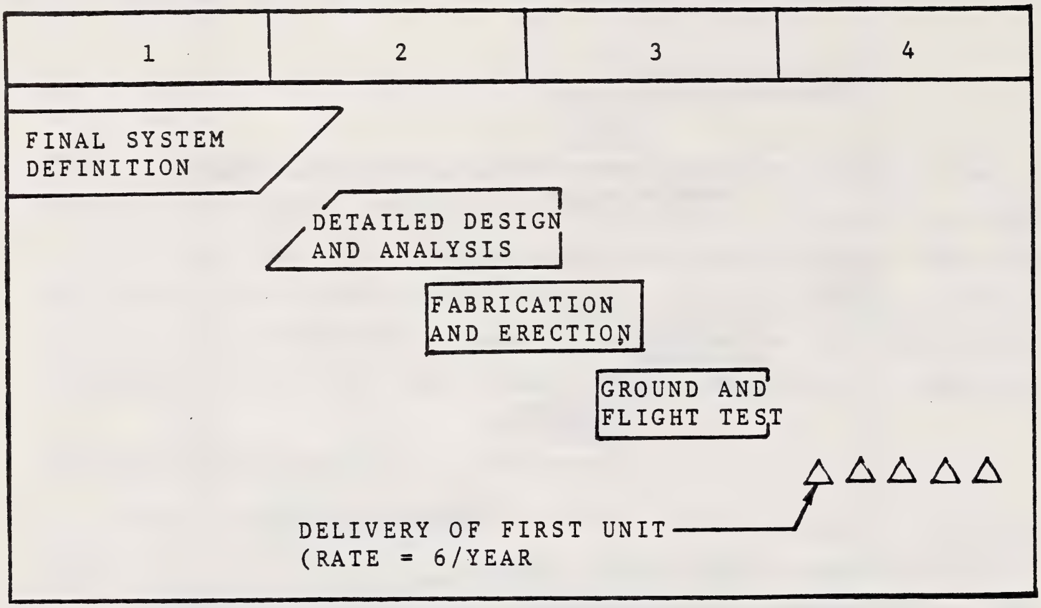


Figure 44. ZPG-X Modern Conventional Airship Production Schedule

of the activities leading to production quantities of the 5K and/or 3W configurations. These two configurations as well as the HLA can be pursued on a parallel basis. Production rates of airships during World War II were considerably higher than collective yearly totals indicated for the HLA and ZPG-X configurations.

5.0 STUDY CONCLUSIONS

The survey and ensuing economic case studies indicate that there are a large number of economically attractive applications for airships in the study area. It is apparent from the surveys and economic case studies that an airship operating company [rental service] is both necessary and economically viable.

The operation of airships within Canada is operationally a viable concept. Environmental factors, while severe in terms of cold, will not appreciably affect airship operations any differently than existing aircraft operating in Canada.

The technology is available to successfully provide vehicles in the near term. Final definition of the vehicles can proceed immediately. Demonstration vehicles are needed to illustrate:

1) A lack of technical and operational risk to users
2) Economic viability
3) Regulatory agency compliance; and
4) To develop user awareness and confidence

It is conservatively estimated that the following vehicle configurations and quantities could be supported by the study area:

Modern Conventional [Non-Rigid]	8 Vehicles
Modern Conventional [Rigid]	2 Vehicles
Heavy Lift	6 Vehicles

The earliest operational availability for the configurations considered during the study is:

Modern Conventional [Non-Rigid]	3 Years
Modern Conventional [Rigid]	8 Years
Heavy Lift Airship	5 Years

As in the case of the modern conventional non-rigid airships there appear to be two sizes of HLA vehicles having near-term applicability. An HLA with a useful load of 45,372 kg [50 tons] would find primary application in some remote construction activities, power line transmission tower erection, and the forest industry. The largest market in the study area for the HLA is probably in the 90,744 kg [100-ton] useful load range. The device would be used primarily in supporting large remote construction projects.

References

1. Feasibility Study of Modern Airships, Phase I, Volumes I, II, III and IV, Goodyear Aerospace Corporation; NASA CR-137692, July 1975.

2. The Impact of Major Resource Projects with Reference to Regional Development in Northeast Alberta
Peter C. Nichols and Associates, Ltd.
April 1976

3. Northeast Alberta Regional Plan - Transportation Network Development Pattern for the Maximum Economic Development Hypothesis
Transportation Working Document No. 18
Stanley Associates Engineering, Ltd.
December 1976

4. Alcan Pipeline Logistics Requirements and Costs
Trimac, Consulting Services Ltd. December 1976

5. Analysis of the Transportation Impact Resulting from the Proposed Arctic Gas and the Alaska Highway Pipeline Proposal

6. Ecomonic Study of Transportation in the Mackenzie River Valley
Travacon Research Limited, Calgary, Canada
Volume I

7. Cost of Transporting Goods into the Mackenzie Valley
Prepared for Arctic Transportation Agency of Transport Canada
by M.P.S. Associates Ltd. Canalog Logistics Limited, July 1977

8. Arctic Oil and Gas by Rail
Volume Two (Book One) - Route Selection and Construction
March 1974

9 Volume Five - Relevant Considerations
March 1974

10. Northern Alberta Transportation Study - Final Report to Steering Committee - September 1976 - Volume I and Volume II

11. Northwest Transportation Plan - 1972

12. Northern Frontier-Northern Homeland
The Report of the Mackenzie Valley Pipeline Inquiry: Volume One
Mr. Justice - Thomas R. Berger - July 1977

13. An Evaluation of the Future Need for Rail Branchlines Proposed for Abandonment
Volume III - Northern Alberta - January 1976

References (Continued)

14. Alaska Highway Pipeline - Report of the Environmental Assessment Panel - Interim Report of the Environmental Assessment Panel to the Honourable Romeo Leblanc Minister of Fisheries and the Environment
July 27, 1977

15. Alaska Highway Pipeline Inquiry
Kenneth M. Lysyk, Chairman, Edith E. Bohmer, Willard L. Phelps
1977

16. North West Rail Authority - A Proposal
Submission to Grain Handling and Transportation Commission on Behalf of the Government of Alberta by the Honourable Dr. H. M. Horner, Deputy Premier and Minsiter of Transportation
September 20, 1976

17. Impact of Further Community Activity on Northeast Alberta
G. M. Young, Northeast Alberta Regional Commissioner's Office
October 1976

18. A Northern Overview for the Department of Industry and Commerce - Government of the Province of Alberta
March 1973

19. Transportation in the Yukon - A Review of Developments 1967 to 1985, Prepared for the Yukon Research and Development Institute Whitehorse by MPS Associated Limited, Winnipeg
August 1973

20. National Energy Board Reasons for Decision Northern Pipelines
Volumes 1, 2 and 3
June 1977

21. Development of Weight Estimating Relationships for Non-Rigid and and Rigid Heavy Lift Airships; Goodyear Aerospace Corporation; NASA CR-151976, March 1977

22. Feasibility Study of Modern Airships, Phase II, Volume I; Goodyear Aerospace Corporation; NASA CR-151917; September 1976

23. Feasibility Study of Modern Airships, Phase II, Volume II; Goodyear Aerospace Corporation; NASA CR-151920; September 1976

CODE IDENT NO. 25500

GOODYEAR AEROSPACE
CORPORATION

AKRON, OHIO 44315

APPENDIX A

AIRSHIP OPERATING COMPANY MODEL

REF: EOT 380

1.0 AIRSHIP OPERATING COMPANY MODEL

1.1 General

The success of airships in civilian applications will depend upon their ability to penetrate applicable markets and produce an equitable rate of return on investment (ROI). Ultimate decisions on the use of airships will be based on comparing modal alternatives, each having different cost and revenue patterns, for selected operating missions. Success in estimating the costs and revenues associated with airship operations will depend upon an accurate description of the economic and operational parameters associated with an airship operating company. Therefore, in exploring world market opportunities for the airship, it is essential that an analysis tool which will accurately portray the economic and operational benefits of an airship operating company be available. Such a tool should have the following attributes:

- Produces results to which a relatively high level of confidence can be attached
- Presents the results in terms of the points of view which exist in a real-world business setting
- Is easy and efficient to use
- Provides a framework to collect and use experience gained from the analyses performed.

The basic model components and interfaces are presented in Figure 1.

The airship operating company model is actually made up of three components or submodels; a company structure model, a company operations model, and an investment model. The company structure and company operations models are primarily descriptive models while

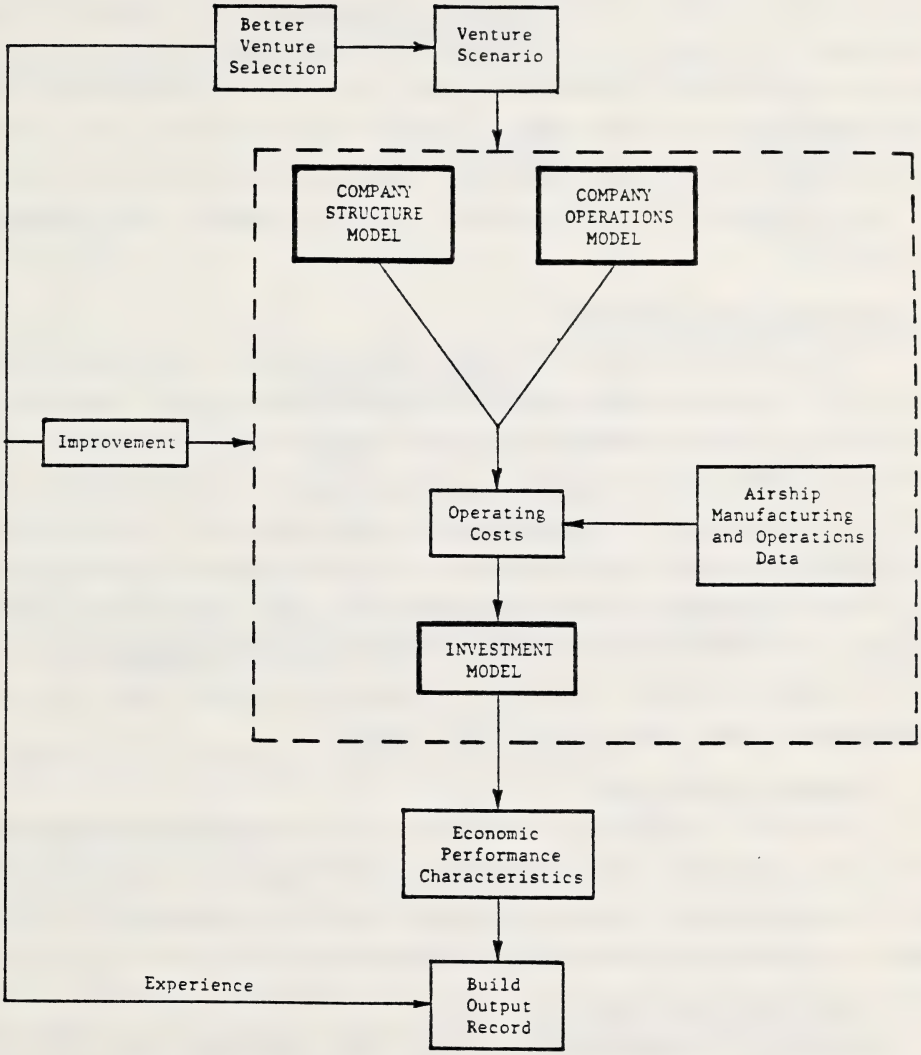


Figure 1. Airship Operating Company Model and Interfaces

the investment model is primarily a computational model. Each model is designed in terms of the points of view which exist in a real-world business setting to produce results to which a relatively high degree of confidence can be attached. These three models will produce an interface with operating cost and manufacturing data to produce a tool which can quickly and efficiently analyze almost any commercial airship venture.

1.2 Company Organization

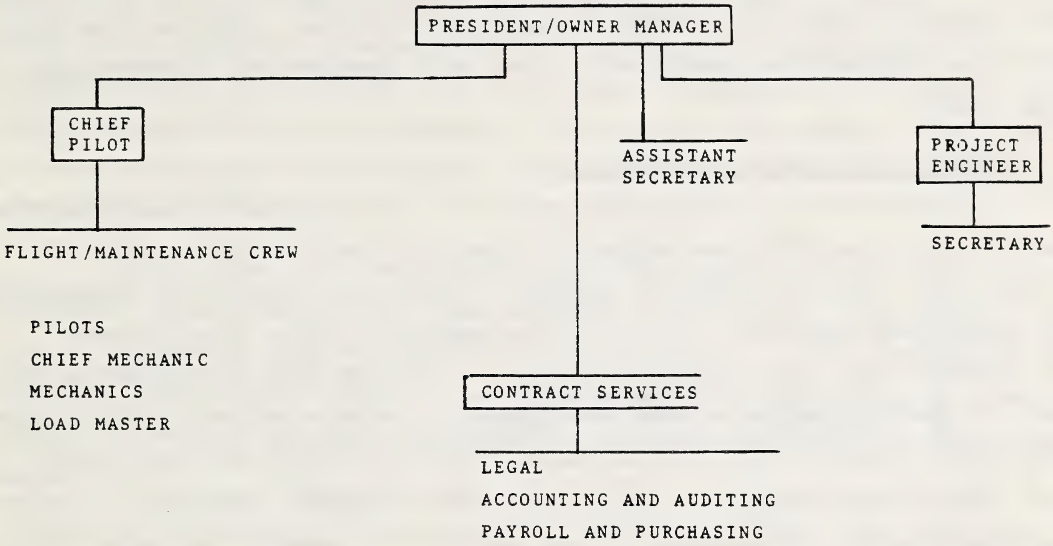
The company formed for the operation of the hybrid airship will require two strong organizational characteristics: mobility and flexibility. The airship's initial markets will involve reactive contracting on projects with very specialized transportation needs. Reactive contracting (being available and ready for operations) demands preparedness and self-sufficiency so that on-site operations can begin with little planning delay and expense. The operating experience developed in this initial phase of market development will eventually lead to improved long-range job planning, longer term contractual arrangements, and lower operating costs.

1.2.1 Company Structure

The early manpower structure of the airship company will be essentially oriented to operations with numerous administrative functions contracted out to appropriate service companies. A typical company structure is shown in Figure 2.

1.2.2 The Corporate Entity

Different corporate entities are possible for the formation of the airship company. Three are discussed below. They are: the independent corporation, the wholly-owned subsidiary, and the consortium-owned operation.



* Number of personnel dependent on number of vehicles, annual utilization, etc.

Figure 2. Typical Company Structure*

1.2.2.1 Private Corporation

The private (independent) corporation is considered the least desirable or realistic form for the airship's operation. There are several initial disadvantages associated with this entity. First the financial strength, the insurability, and the survivability would be in doubt before operations ever began. The economic penalties associated with the above might prove so insurmountable for a new venture, as to preclude its development.

1.2.2.2 Wholly-Owned Subsidiary

The wholly-owned subsidiary of an existing transportation related company offers several advantages to a new operating venture.

A strong, well-established corporate base is in a position to leverage financial support, solicit favorable insurance rates, provide the contract services needed for administration, and furnish an experienced marketing staff.

1.2.2.3 Consortium-Owned Operation

A consortium of potential users of the airship's capabilities is formed to provide the same support cited in the wholly-owned subsidiary section. The consortium concept, however, offers one additional superior marketing quality - vertical integration into consortium-member's operations. One important key to success for the airship is the level of user acceptance and dependency. Once a major construction or mining corporation, etc. assimilates the use of the airship into their job specifications, the future use and expanded markets for airships is practically guaranteed. The concept of consortium ownership also provides for greater financial risk spreading and greatly increased economic base for financing airship construction and operation.

1.3 Company Operations

1.3.1 Operational Planning

The ideal time for airship operational planning to begin is with a potential customer's project design phase. It is at this point that a comparison of the airship's capabilities and operational parameters can be made with the customer's construction or production requirements. This exchange of data permits the timely identification of critical transportation factors in an operation, so that possible beneficial changes in either airship parameters or project design can be accommodated.

Since entry into this ideal situation can usually only be achieved by a transportation company with operating experience, especially with such a new mode of transport, it will be necessary for the airship to build a base of operating experience. This requires the airship operating parameters to be flexible and adaptive to a wide variety of industry transportation needs. The refinement of the airship capabilities, reliability, and economics will improve as operating experience increases. This will then permit the data to be inserted into the earliest project design process with greater customer confidence.

Until these operating data are developed, the airship will normally enter service at some specific project's operational phase (e.g., to move heavy equipment to a new site). This reaction contracting aspect requires a thorough premission planning process. A typical premission planning outline is described on the following pages.

PREMISSION PLANNING FOR AIRSHIP OPERATION

Establish Job Requirements

- Location of Load Pickup/Drop Sites
- Type of Cargo
- Volume of Cargo
- Average Unit/Load Weight
- Distance to be Transported
- Time Constraints
- Any Special Handling or Environmental Requirements

Site Inspections

- Pickup/Drop Sites (to Include Maps, Photos, Obstructions, etc)
- Equipment Necessary for Handling Airship Loads at Both Sites
- Details of Other Operations Being Conducted at Sites

Route Survey

- Identification of En Route
  - Terrain hazards
  - Obstructions to flight
  - Populated areas
  - Emergency landing sites
- Navigation Aids Available/Necessary
- Flight Following Requirement
- General Weather Considerations

Facility Requirements

- Airship Mooring
- Maintenance and Refueling Service
- Crew Quarters

Control and Communications

- Site Control (All Personnel and Equipment)
- Load Pickup/Drop Coordination
- Communications
  - Intracrew (airship)
  - Intercrew at sites
  - Weather monitoring
  - Home base contact
  - En route flight following

Safety

- Emergency Procedures for Airship
  - In flight
  - Pickup/Drop Sites
- Flight Crew and Load Crew Training
- Identification of Operational Hazards
- Procedures for Handling Hazardous Materials
- Accident Reaction Planning

1.3.2 Mission Plan

The information that is gathered in the premission planning phase can then be fully evaluated in relation to the airship's capabilities and a detailed mission plan developed. This mission plan would provide firm airship productivity and cost factors in which a final firm contract can be formed. The mission plan translates the premission data into the following information.

Job Specifications

- Best Pickup/Drop Site Locations
- Average Load Weight and Volume
- Number of Airship Flight Hours
- Completion Times
- Necessary Accessory Equipment
- Number of Personnel (Airship Crew)
- Number of Personnel (Customer)
- Energy Requirements
- Airship Basing Requirements
- Operational Control

Route

- Best Route Combination
  - Energy efficient (direct)
  - Avoiding populated areas when possible
  - Emergency landing site availability

Safety

- Accident Response Procedures and Individual Responsibilities

Costs

- Total Cost of Operation

1.3.3 Standard Operating Procedures (SOP's)

The premission planning table also gives the project engineer and chief pilot sufficient time to organize, equip, move, and establish the airship's new base of operations. The time involved in this process will be necessarily short. When a major construction project is being held up, the delays can be costly. Thus, the airship company will have to have certain SOPs.

- Self-sufficient in the field for extended operations (one week or longer in duration)
- Carry maintenance and supply pods for all operations
- Portable mooring facilities (pod transportable)
- Crew quarters pod
- A substantial unrefueled flight capability
- A portable communications/navigation system
- A cargo pod (fixed point/aerodynamically streamlined for carrying mixed cargo loads.

These seven items by no means represent a complete SOP that can only be developed with firm plans and operating experience. The items do, however, reflect the need to be mobile and flexible for the airship's initial entry into this market. The operator of this craft can expect to operate in remote areas where terrain and climate combine to create special transportation problems and where conditions are considered spartan and even primitive.

1.4 Investment Model

In order to evaluate the economic performance of the airship operating company, an investment model was developed which utilizes discounted cash flow techniques. A cash flow occurs when money actually changes hands from one individual/organization to another. Thus, money received and money dispersed constitutes cash flows.

By calculating the annual cash flows over the life of the vehicle and discounting each of these flows, the return on investment (ROI) for a fixed revenue yield can be determined. Alternatively, the model can be used to determine the revenue yield required for the heavy-lift airship to produce a certain ROI.

The logic flow of the investment model is described schematically in Figure 3. Table I itemizes the model inputs and Table II the model outputs. The details of this model are discussed below.

1.4.1 Model Description

1.4.1.1 Depreciation

An airship operating company would be free to depreciate the investment in any of a number of ways allowed by the Government. The model incorporates three such schedules, any of which can be selected. Figure 4 provides the equations and an example. It has been the habit of Air Transport Association (ATA) to use Double Declining to Straight Line because of the large depreciation allowed in the first year. From

TABLE I - INVESTMENT MODEL INPUTS

Name	Variable	Units
Cost	Total operating cost	$/year
Inv	Total capital investment	$
SL	Service life	Years
DS	Depreciation schedule 1 = Straight line 2 = Sum of years digits 3 = Double declining to straight line	--
DP	Depreciation periods	Years
RV	Residual value	Percent/100
REVHI	Max revenue guess	$/year
REVLO	Min revenue guess	$/year
N3	Loan period	Years
TR	Tax rate	Percent/100
ITC	Investment tax credit	Percent/100
PERFIN	Percent financed	Percent/100
PERINT	Percent interest	Percent/100
IFLAG	Type of interest 1 = Simple interest 2 = Compound interest	--
ITER	Max number of revenue adjustments	--
PRTDIAG	Print diagnostics	--
Z	ROI guess	Percent/100
DROI	Desired return on investment	Percent/100

TABLE II - INVESTMENT MODEL OUTPUTS

Name	Variable	Units
P	Period	Year
Rev	Revenue	$/year
Cost	Total operating cost	$/year
D(P)	Depreciation	$/year
T(P)	Taxes	$/year
A(P)	After tax profit	$/year
CF(P)	Cash flow	$/year
ACF(P)	Accumulated cash flow	$/year
(P)	Return on investment	$/year

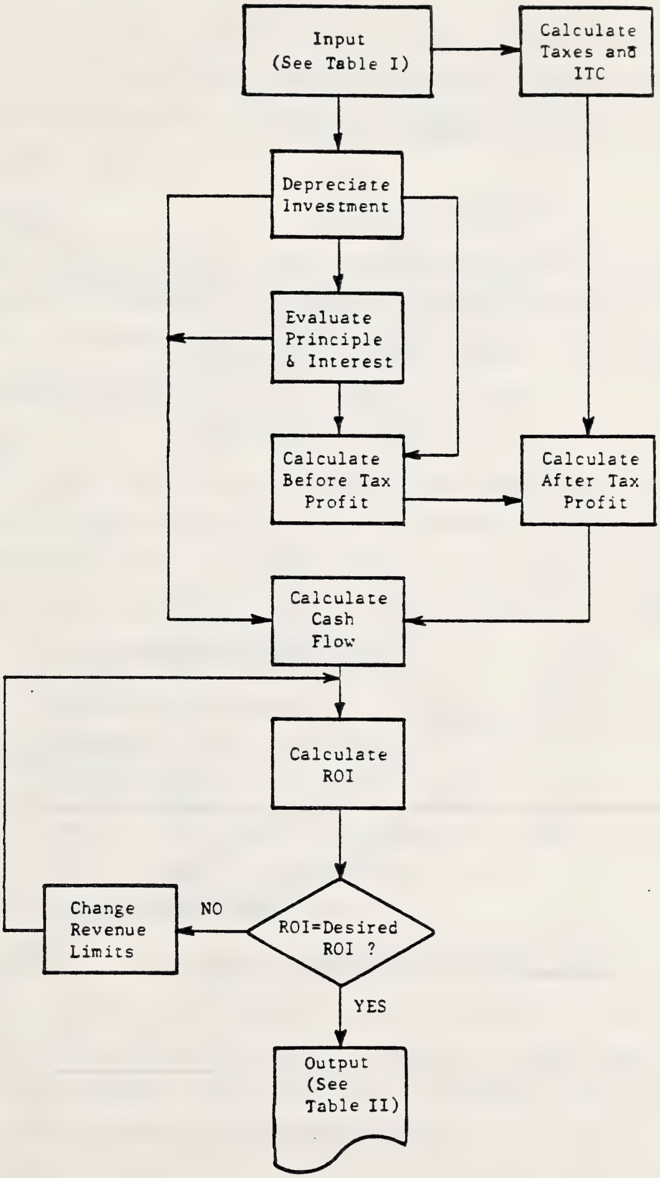


Figure 3. Logic Flow of Investment Model

Investment = I = \$8,000,000

Depreciation Period = D4 = 8 yrs

Residual Value = R9 = zero

Straight Line

$\text{Dep/yr} = I*(1-R9)/D4$

Sum of Years Digits

$\text{Dep/yr} = (D4-YR+1)/(\text{sum of digits})*I*(1-R9)$

Double Declining to Straight Line

$\text{Dep/yr} = ((1-2/D4)^{(YR-1)})*(2/D4)*I*(1-R9)$

for 1st half of Dep. Period

$\text{Dep/yr} = ((1-2/D4)^{(YR-1)})*(1/(D4-YR+1))*I*(1-R9)$

held constant at the D4/2+1 YR value
for 2nd half of Dep. Period

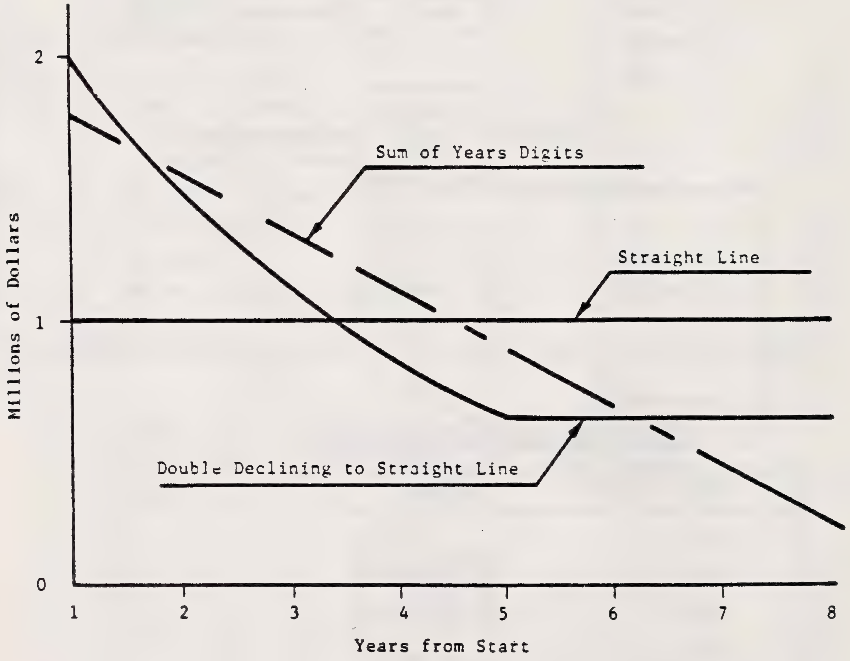


Figure 4. Examples of Depreciation Procedures

the example, it is seen that the Sum of Years Digit (1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 = 36 in this case) would probably be equally beneficial. Test runs can always be made to find the depreciation schedule that results in the highest ROI.

1.4.1.2 Loan Payment

The model incorporates two algorithms for calculating loan principal and interest payment. Either a simple interest or compound interest method can be selected. In either case, the calculations are made on an annual basis.

1.4.1.3 Cash Flow

The model finds the yearly cash flow realized by the operator and discounts this to find return on investment or discounted rate of return. It is necessary to be clear about what cash flow includes and Figures 5 and 6 are provided for this purpose.

TOC = Total Operating Cost
IP = Interest Payment
PP = Payments on Principal
DEP = Depreciation
Before Tax Profit (BTP) = Revenue - TOC - IP - DEP
Taxes = BTP x Tax Rate + (Dep. - PP).
ROI = Return on Investment

The cash flow, for any given year, is the amount left after taxes plus that set aside and called depreciation. From this must be subtracted the PP. The depreciation is part of the cash flow into the company because it is money they are able to keep their hands on. Hence, the desire to depreciate the investment as rapidly as possible. It means money in their hands to work with, money that can be used to generate additional capability and, hopefully, additional revenue.

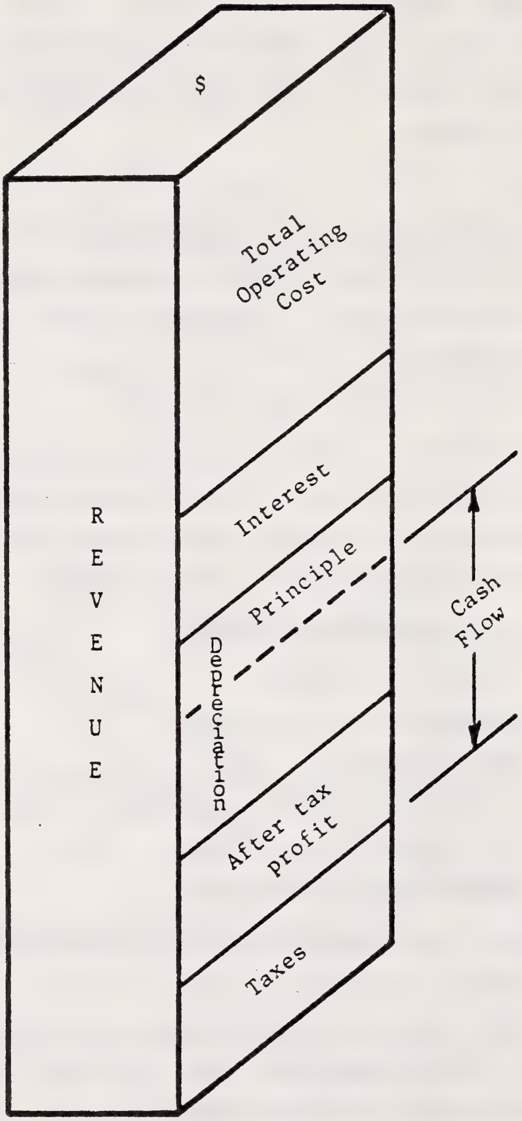


Figure 5. Relationship Between Economic Parameters

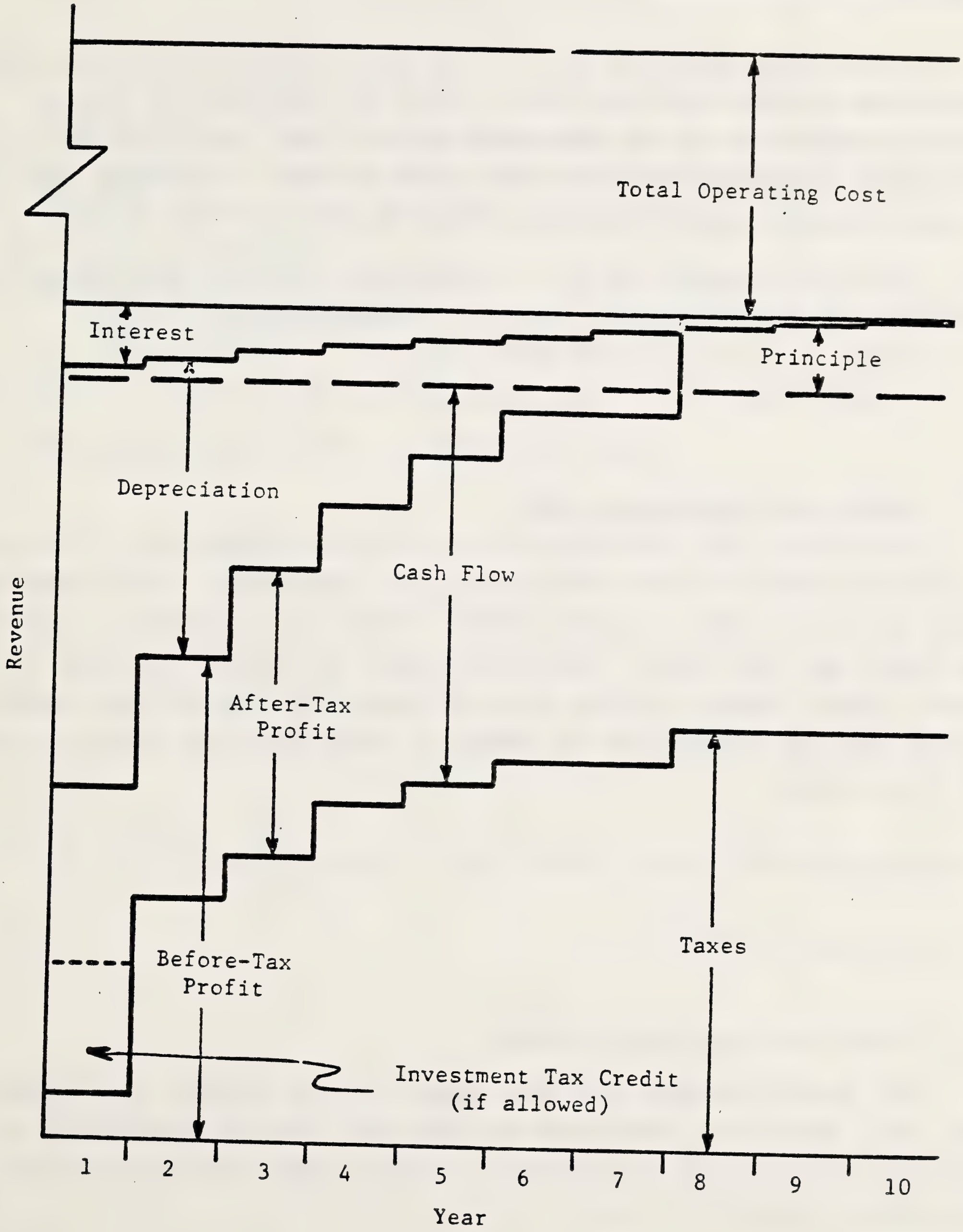


Figure 6. Variation in Economic Parameters Over Time

It is seen that the use of the word 'profit' confuses rather than clarifies. The After Tax Profit does not include the amount depreciated, which can be an important part of the cash flow and it is cash flow that goes into the determination of ROI. A company can show a low profit figure while enjoying a very good cash flow and ROI.

The above equations can be combined to yield the following expression which may also help explain the situation.

$$\text{Cash Flow} = (1 - \text{Tax Rate})(\text{REV.} - \text{TOC} - \text{IP}) + (\text{Tax Rate})(\text{DEP.}) + \text{INV. Tax Credit} - \text{PP}$$

1.4.1.4 Return on Investment (ROI)

The ROI is the end point of the economic analysis. The label ROI is used a number of different ways and, therefore, it is important to define how it is used in this model. Here it is actually a rate that is found and the label 'Discounted Rate of Return' is more informative. This 'rate' is that rate at which the sum of the yearly cash flows must be discounted in order to make this sum equal to the initial investment.

$$\text{INV.} = \text{C.F.1}/(1 + R)^{.5} + \text{C.F.2}/(1 + R)^{1.5} + \text{C.F.3}/(1 + R)^{2.5} + \text{C.F.4}/(1 + R)^{3.5}{}^{*}$$

ROI = R when the equation balances.

The model assumes that the cash flow is uniform throughout the year and, therefore, the time is from the initial investment to the midpoint of the year in question. Hence, the exponents of 0.5, 1,5, etc. rather than 1, 2, etc.

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[*] C.F.1 = Cash flow for year 1, C.F.2 = cash flow for year 2, etc.

In this model, the ROI is considered to be the return on the out of pocket (or unborrowed) portion of the total investment. The ROI is, therefore, the return on the partys' investment after he has paid off his interest and principal obligations. It is not the return on the total investment.

1.4.1.5 Model Mechanization

The investment model has been mechanized as a computer program.

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APPENDIX B

PARAMETRIC ANALYSIS OF TOTAL OPERATING COSTS OF HEAVY LIFT AIRSHIPS

1.0 HLA TOTAL OPERATING COSTS

1.1 General

An estimate of the HLA Total Operating Costs (TOC) has been completed to support the case study analysis. The TOC analysis considers an operational configuration shown conceptually in Figure 1. This differs from the recommended demonstration configuration (discussed later) shown in Figure 2 in two primary respects. The demonstration configuration uses existing helicopter assets that could be obtained at no out-of-pocket costs to the development program. In the demonstration configuration the crew is accommodated in the helicopters.

The operational configuration of Figure 1 utilizes propulsive lift modules thereby eliminating the superfluous components of the helicopters and accordingly reducing vehicle weight and acquisition costs. Other possible economic benefits that accrue through use of the propulsive lift modules are developed in the balance of this TOC analysis.

The TOC analysis has been developed for vehicles ranging in size from a useful load (payload + fuel) of 45,372 kg (50 tons) to a useful load of 408,348 kg (450 tons). Non-rigid airship hull construction has been considered for useful loads up to 142,468 kg (150 tons) whereas rigid hull construction has been considered for the larger vehicles. The reason for the change in hull construction is discussed in Reference 1 prepared by Goodyear for NASA. The TOC for the non-rigid configuration is documented in Section 2 below whereas the TOC analysis for the rigid configurations is presented in Section 3.

The TOC analysis considers parametric variations in both quantity of vehicles produced and hours of utilization per annum as discussed subsequently. Quantities of production vehicles considered were 1,

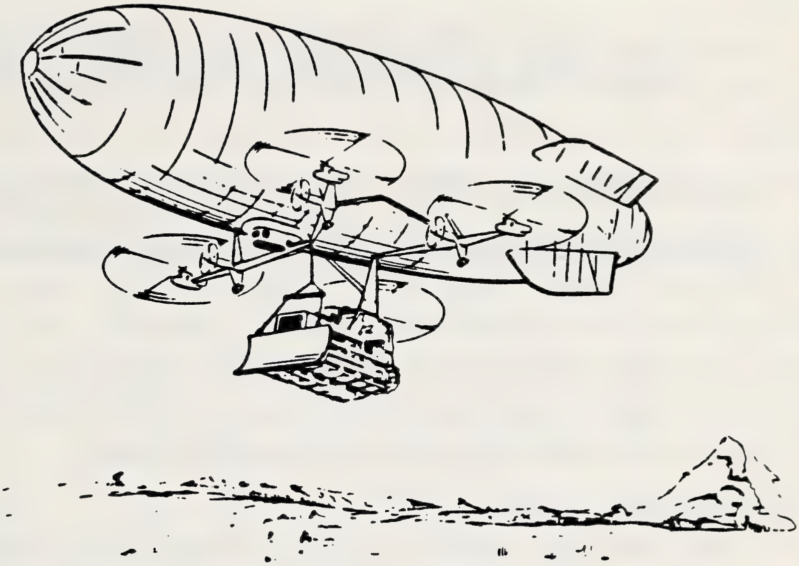
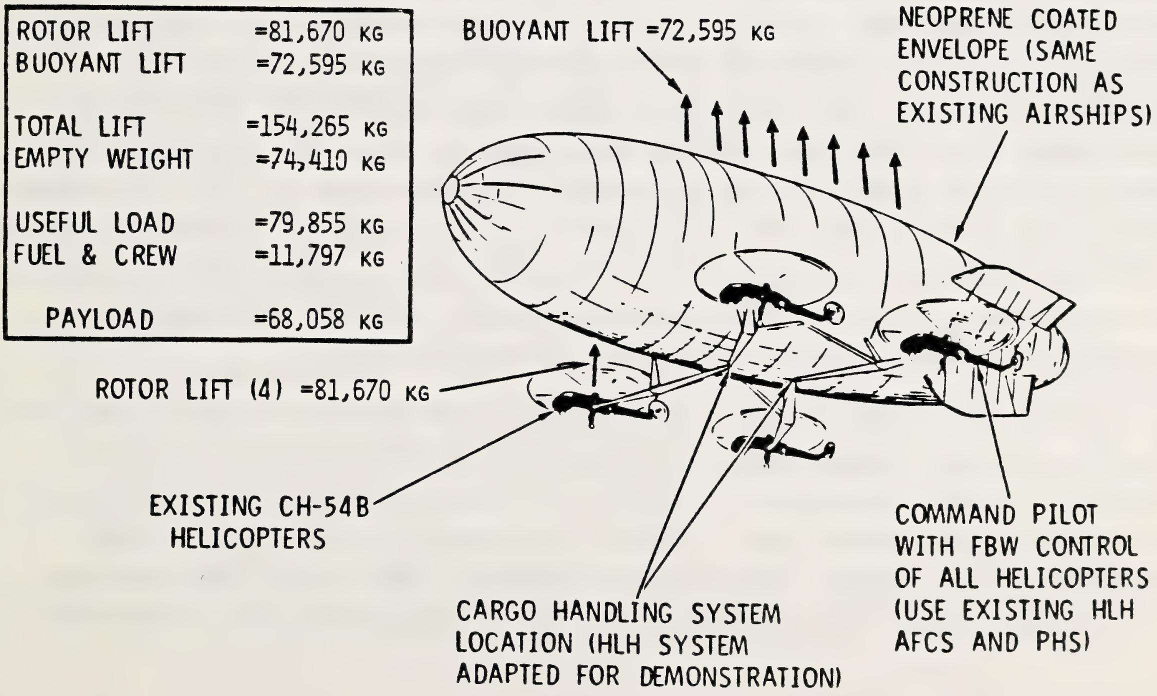


Figure 1 - Heavy Lift Airship Operational Configuration



ROTOR LIFT	=81,670 KG
BUOYANT LIFT	=72,595 KG
TOTAL LIFT	=154,265 KG
EMPTY WEIGHT	=74,410 KG
USEFUL LOAD	=79,855 KG
FUEL & CREW	=11,797 KG
PAYLOAD	=68,058 KG

BUOYANT LIFT =72,595 KG
NEOPRENE COATED ENVELOPE (SAME CONSTRUCTION AS EXISTING AIRSHIPS)
ROTOR LIFT (4) =81,670 KG
EXISTING CH-54B HELICOPTERS
COMMAND PILOT WITH FBW CONTROL OF ALL HELICOPTERS (USE EXISTING HLH AFCS AND PHS)
CARGO HANDLING SYSTEM LOCATION (HLH SYSTEM ADAPTED FOR DEMONSTRATION)

Figure 2 - Heavy Lift Airship Demonstration Configuration

5, and 25 while annual utilizations varied between 1000 and 3000 hours. A sensitivity analysis is also included in Section 2.4.

2.0 TOTAL OPERATING COSTS (TOC) FOR NON-RIGID HLA'S

2.1 Direct Operating Costs (DOC) for Non-Rigid HLA's

The DOC model used is the standard ATA* approach for establishing the vehicle direct operating costs. Briefly, the DOC includes those items related directly to acquiring and operating the vehicle. It should be noted that the ATA format does not include the cost of money to acquire the vehicle and associated spares.

2.1.1 Flyaway Costs

The vehicle component and assembly costs were developed for the twenty-six component groups listed in Table I. The costs of the component groups summarized in Table I were developed from Cost Estimating Relationships (CER's) which are based primarily on component weight. Table II summarizes the component weights for the vehicle sizes considered. The component weights were generated from Weight Estimating Relationships (WER's) generated by Goodyear during a previous study for NASA and are documented in Reference 1. The reference WER's were modified to include recent modifications to the HLA configuration (auxiliary propulsion system and empennage). As noted in Reference 1, the weights of the propulsive lift module (rotor, transmission, engines, etc.) were based upon WER's from Reference 2.

The CER's used for the propulsive lift module, Items 9, 10, 11, 12, 13, 14, 15, 16, and 18, of Table I, were taken from a report currently under preparation for a U. S. Government agency and reflect the most comprehensive set of CER's available for helicopters and helicopter components. Helicopter component CER's were used because of the significant similarity of the above components with those of

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*American Transport Association

TABLE I - VEHICLE COMPONENTS AND ASSEMBLY COST (IN MILLIONS OF DOLLARS) VS USEFUL LOAD AND QUANTITY (NON-RIGID)

Item No.	No. of Units	1			5			25		
	Useful Load (kg)	45,372	90,744	142,468	45,372	90,744	142,468	45,372	90,744	142,468
1	Outriggers	3.31	5.85	8.46	11.69	20.59	29.79	41.08	72.47	104.87
2	Star Frame	0.96	1.75	2.92	3.37	6.15	10.29	11.86	21.64	36.22
3	Envelope	1.76	3.42	5.51	5.77	11.23	18.17	19.19	37.60	61.20
4	Suspension System	0.031	0.062	0.11	0.153	0.31	0.53	0.77	1.56	2.66
5	Ballonets & Air Lines	0.011	0.023	0.040	0.057	0.12	0.20	0.28	0.58	0.99
6	Miscellaneous Envl.	0.011	0.023	0.039	0.056	0.12	0.20	0.28	0.58	0.98
7	Pressure System	0.44	0.89	1.52	1.50	3.07	5.22	5.15	10.51	17.90
8	Control Car	0.44	0.44	0.44	1.40	1.40	1.40	4.42	4.42	4.42
9	Landing Gear	0.59	1.20	1.98	1.95	3.96	6.54	6.53	13.30	21.96
10	Propulsion Pod Structure	2.36	4.83	7.71	7.44	15.25	24.34	23.46	48.12	76.81
11	Flight Controls	0.17	0.30	0.45	0.72	1.31	1.94	3.12	5.68	8.39
12	Equipment (Hyd, Elec. Pneu)	0.21	0.27	0.31	0.91	1.16	1.36	3.93	5.02	5.88
13	Rotor Systems	0.62	1.52	2.68	3.12	7.62	13.42	15.59	38.12	67.10
14	Drive Systems	0.55	1.37	2.42	2.76	6.85	12.08	13.80	34.23	60.40
15	Engines	2.40	4.08	5.13	7.99	13.76	17.22	26.24	46.00	57.29
16	Engine Instal.	0.99	1.65	2.3	3.13	5.22	7.26	9.89	16.46	22.90
17	Instruments - Navigation	0.025	0.025	0.025	0.12	0.12	0.12	0.61	0.61	0.61
18	Instr.-Eng., Trans. Hyd	0.080	0.080	0.080	0.40	0.40	0.40	2.01	2.01	2.01
19	Misc. Inst.	0.026	0.026	0.026	0.13	0.13	0.13	0.64	0.64	0.64
20	Electronics	0.040	0.040	0.040	0.17	0.17	0.17	0.75	0.75	0.75
21	Furnishings	0.013	0.013	0.013	0.059	0.059	0.059	0.25	0.25	0.25
22	Air Conditioning	0.068	0.068	0.068	0.29	0.29	0.29	1.26	1.26	1.26
23	Empennage	1.26	2.91	4.53	4.44	10.26	15.94	15.64	36.10	56.12
24	Auxiliary Propulsion	0.89	1.32	1.84	3.12	4.63	6.49	10.99	16.30	22.83
25	FBW Control System, AFCS, IMU, SAS, Stick Force Feel System, Empennage Actuators	0.46	0.46	0.46	2.3	2.3	2.3	11.5	11.5	11.5
26	Helium	0.027	0.027	0.027	0.136	0.136	0.136	0.68	0.68	0.68
27	Vehicle Erection & Assy	4.44	8.16	12.28	15.80	29.15	44.00	57.48	106.60	161.66
28	TOTAL	22.18	40.80	61.41	78.98	145.77	220.00	287.40	532.99	808.28
29	UNIT COST	22.18	40.80	61.41	15.80	29.15	44.00	11.50	21.32	32.33

TABLE II - NON-RIGID HEAVY LIFT AIRSHIP COMPONENT WEIGHTS - kg

Item No.	Useful Load - (kg)	45,372	90,744	142,468
	Hull Volume x 10 ^{6} m^3	0.038	0.08	0.132
	No. Rotors	4	4	4
	Rotor Dia. - m	17.2	24.3	30.5
	Buoyant Lift* - kg	38,247	79,307	131,334
1	Outriggers	6,342	13,308	21,559
2	Star Frame	2,065	4,555	7,620
3	Envelope	5,240	11,037	17,940
4	Suspension System	1,432	2,924	4,979
5	Ballonets & Air Lines	548	1,186	1,905
6	Miscellaneous Envl.	542	1,108	1,870
7	Pressure System	808	1,651	2,812
8	Control Car	680	680	680
9	Landing Gear	4,136	8,425	13,911
10	Propulsion Pod Structure	1,515	3,534	6,135
11	Flight Controls	523	954	1,408
12	Equipment	727	929	1,088
13	Rotor System	4,079	9,505	16,484
14	Drive System	4,561	10,563	18,255
15	Engines	1,476	2,449	3,406
16	Engine Instl.	369	612	851
17	Instruments - Navigation	40	40	40
18	Instr.-Eng., Trans., Hyd	317	317	317
19	Misc. Inst.	101	101	101
20	Electronics	121	121	121
21	Furnishings	84	84	84
22	Air Conditioning	141	141	141
23	Empennage	1,683	5,015	8,921
24	Auxiliary Propulsion	734	1,210	1,859
25	FBW Control System, AFCS, IMU, SAS, Stick Force Feel System, Empennage Actuators	227	340	454
26	Crew **	272	272	272
	EMPTY WEIGHT	38,763	81,061	133,213

*Sea Level Std Day
**Crew considered part of Empty Weight for simplicity.

a helicopter. The helicopter CER's were checked prior to use in this study in estimating the price of a large helicopter similar in thrust output to the thrust levels required for the propulsive lift modules of the HLA vehicles studied herein. With the assembly and profit allowance of Reference 3, an extremely close match was obtained between the check case and recent price quotations by the manufacturer of the helicopter in question.

In the case of the rotor group and the drive system group, no learning curve effects were included because the data base used to develop the CER's were inconclusive in this respect. There is unquestionably a learning curve effect; therefore, the acquisition cost for the rotor and drive system groups is conservative for quantities greater than 1.

The helicopter component CER's were also used to estimate the costs of Items 8, 17, 19, 20, 21, and 22 because of the similarity between these items and corresponding items of a helicopter.

The CER's used for Items 3, 4, 5, 6, and 7 of Table I are based upon existing techniques at Goodyear for parametrically establishing non-rigid airship costs.

The CER's used for Items 1, 2, and 23 of Table I were taken from Reference 3 for transport aircraft because of similarity of the construction of these items with wing, tail and alighting gear structures of transport aircraft.

The CER's used for Item 24 of Table I are CER's used for turboprop aircraft propulsion group components.

The cost of components included in Item 25 of Table I are based on recent price information on these items.

A vehicle assembly and erection allowance consistent with Reference 3 has been considered herein for the HLA's. This allowance includes individual vehicle acceptance costs.

It should be noted that the component CER's account for the costs of such items as component manufacturing facilities, component production tooling, component RDT&E* and certification costs and profit. Vehicle RDT&E and certification costs are considered separately below. Manufacturing facilities costs for final assembly and erection of the vehicle are considered separately in Section 2.2.

The CER's do not include spares, and vehicle support equipment. These items are accounted for separately in the following sections of this TOC analysis.

2.1.2 Vehicle Development Costs

As noted previously, the CER's reflect component development costs with the exception of Items 3, 4, 5, 6, and 7 of Table I. It should be noted that this is only true when a system reflecting current technology is being costed since the CER's are based upon the cost of currently built aircraft and aircraft components. In all cases involving the non-rigid HLA's only current technology is being considered. This comment includes the propulsive lift module which is based upon existing helicopter technology.

It is believed that the approach of considering only existing technology should be followed in generating the total operating costs in order to maintain maximum credibility. This is not to suggest that advanced technology cannot improve the economics or other attributes of the HLA for obviously it can. It is believed highly unlikely, however, that foreseeable technological improvement could make the difference between current economics being not viable and future economics being viable in the market place. It is believed, that foreseeable technological improvements can be expected to expand the market not make it.

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*Excluding Items 3, 4, 5, 6, and 7. See Section 2.1.2

The structure of this TOC analysis permits a convenient method for assessing, on a sensitivity basis, the economic benefit attendant with technological development based on the cost of that development as a function of number of vehicles produced and annual utilization.

The RDT&E costs associated with the HLA vehicle have been estimated on the basis of the HLA development program generated by Goodyear for NASA as summarized in Reference 4. Some revisions to that plan have been made based upon the results of technical assessments since that time. The development program considered herein is summarized in Figure 3.

As noted in Figure 3, it is believed that a demonstration of the technical, operational, and economic viability of the HLA concept is needed to establish user, operator, and regulatory agency confidence in the concept. On the basis of cooperative venture basis, it is believed that if full advantage is taken of existing assets that a 68,058 kg (75-ton) payload demonstration vehicle can be developed within four years at an estimated contractor cost of $25 million.

This vehicle, once developed, would be used for military/civil demonstrations under actual operating conditions. Following such demonstrations the vehicle would be used for full-scale research purposes and as a test bed for assessing configuration changes and technological improvements. The only configuration changes considered essential prior to a production design being available is the replacement of the helicopters of the demonstration vehicle with a propulsive lift module. It is currently not clear whether it would be necessary for a contractor to fabricate a prototype of the production configuration. If needed, the helicopters from the demonstration vehicle would

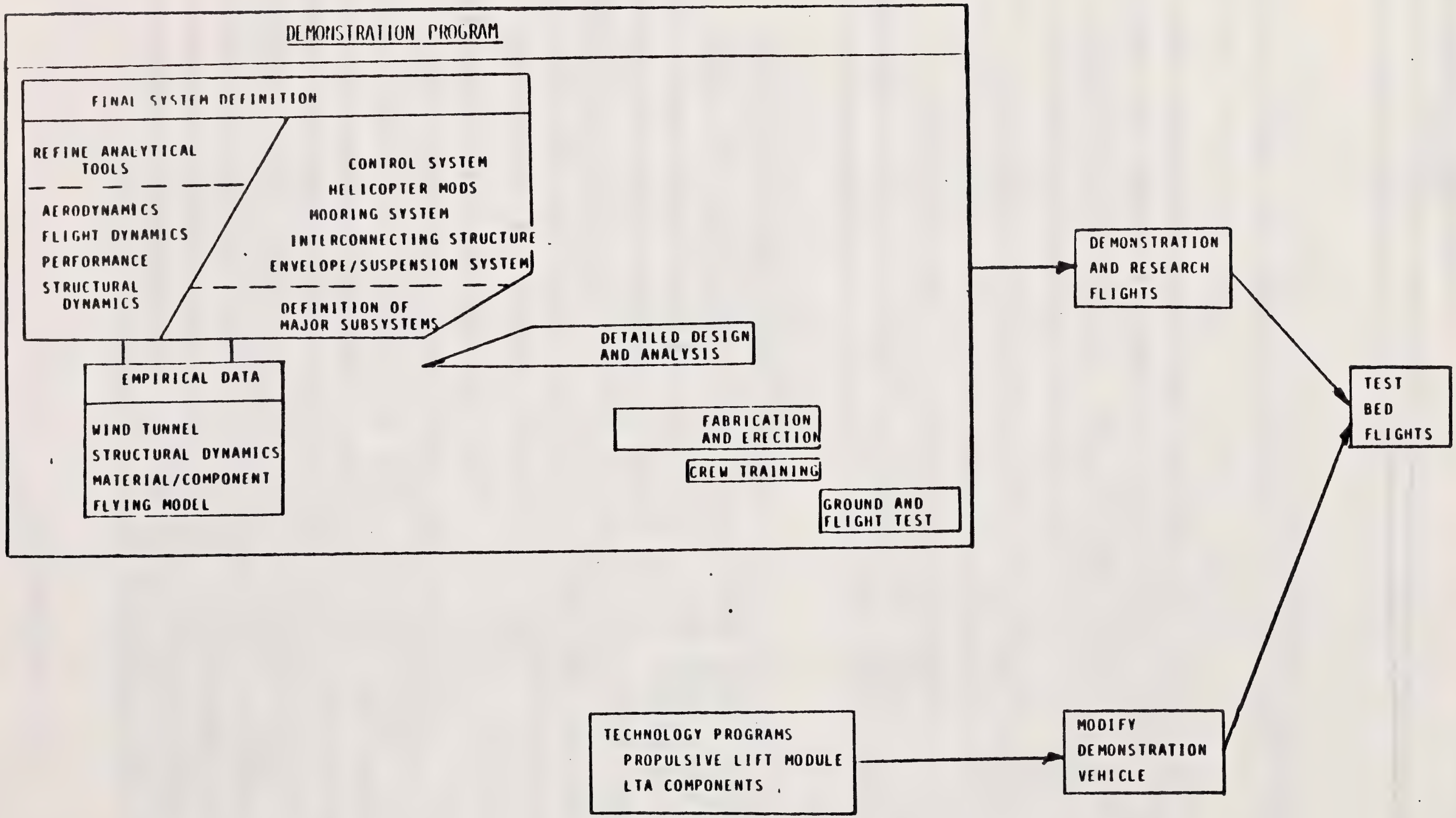

Figure 3 HLA Development Plan

be demated and the propulsive lift modules interfaced with the test bed vehicle as well as a control car added. The impact on TOC of this additional RDT&E expense is addressed subsequently in the sensitivity analysis of Section 2.4.

The RDT&E costs of Items 3, 4, 5, 6 and 7 of Table I are included within the demonstration program as defined in Figure 3.

2.1.3 Vehicle Certification Costs

Section 2.1.1 indicated the CER's that included component certification allowances. Certification costs for the HLA vehicle are somewhat difficult to establish since there are currently no established regulations for such devices which is one major reason a demonstration vehicle is needed. The buoyancy, multiplicity of power plants and auxiliary propulsion system suggest extremely low probability of safety of flight concerns. Additionally, the vehicle will not carry personnel for hire which will tend to reduce certification time and expense. The present assessment is that certification costs for vehicles up to the 142,468 kg (157-ton) useful load capacity will be on the order of $10 million. In the subsequent sensitivity analysis the impact of larger certification costs are considered. As discussed in Section 3, certification costs for large vehicles are expected to increase beyond the $10 million figure.

2.1.4 Total Aircraft Costs

Total aircraft costs are summarized in Table III. The development and certification costs, as summarized above, were amortized over the various vehicle quantities considered and added to the vehicle flyaway cost for those same quantities. The cost of the ground equipment required to handle the vehicle at the point of manufacture has also been included and amortized over the quantities of vehicles produced. Manufacturing facilities in which to assemble and erect the

TABLE III – TOTAL VEHICLE COSTS (MILLIONS OF DOLLARS)

COST ELEMENT	Quantity								
	1			5			25		
	U.L. - (kg)								
	45,372	90,744	142,468	45,372	90,744	142,468	45,372	90,744	142,468
1. Vehicle Component Fabrication and Assy	22.21	40.86	61.49	79.12	146.05	220.42	288.1	534.1	810.38
2. Vehicle RDT&E	25	25	25	25	25	25	25	25	25
3. Vehicle Certification	10	10	10	10	10	10	10	10	10
4. Ground Support Equipment*	1.25	1.50	1.75	1.25	1.50	1.75	2.50	3.00	3.50
5. Manufacturing Facilities (Vehicle Assembly & Erection)	2	2	2	5	5	5	15	15	15
TOTAL	60.46	79.36	100.24	120.37	187.55	262.17	340.60	587.10	863.88
6. Total Cost/ Vehicle	60.46	79.36	100.24	24.07	37.51	52.38	13.62	23.49	34.55

* Refers to equipment required at point of manufacture.

vehicle are also included and amortized over the quantity of vehicles produced. These facilities costs are costs required to refurbish existing contractor facilities. Large quantities of vehicles could necessitate new facilities.

2.1.5 Insurance Costs

Annual insurance costs were taken at 4% of the total aircraft costs which is twice the ATA rate for conventional aircraft and one-half that typically applied to helicopters.[***] It is believed that the insurance rate for the HLA will be much less than that typical for helicopters because of the inherent fail safe feature that the buoyancy and multiplicity of power plants provides. Additionally, the auxiliary propulsion system and empennage permit the HLA to be flown as a conventional airship if all rotors were inoperative. The demonstration vehicle will be essential in establishing a data base of flight experience upon which insurance rates can be based.

[***] There are helicopters currently operating in the U. S. construction industry that have annual insurance rates as low as 3%.

These insurance costs do not include the cost of insuring the payload as that is not a vehicle-related cost.

2.1.6 Vehicle Depreciation

The vehicle has been depreciated to 25% residual value over a 12-year period which is typical of helicopter experience. Conventional aircraft are typically depreciated over a 15-year period. The fabric components of the vehicle, based upon actual airship experience and experience of similar fabrics under similar conditions can be maintained for this period.

Spares allocation is as follows:

A. Propulsive life module at 30% of lift module cost (Items 9, 10, 11, 12, 13, 14, 15 and 16 of Table I) which is typical of helicopter practice.

B. Auxiliary propulsion system at 30% of system cost which is typical ATA practice for turboprop aircraft.

C. Balance of aircraft at 6% which again is typical ATA practice for conventional aircraft.

In the sensitivity analysis accompanying this TOC investigation, the impact of amortizing the vehicle over a 15-year period is examined because the operational life of the propulsive lift module can be increased over that typical for helicopters because of reduced forward speed and the ability to utilize higher design margins in the dynamic components than in the case of helicopters.[*] Marginal increases in weight that would be expected because of the higher design margins would be offset by a slightly larger aerostat.

2.1.7 Direct Maintenance

2.1.7.1 Airframe

Direct maintenance labor and material costs for the HLA airframe (Items 1, 2, 17, 18, 19, 20, 21, 22, 23 and 25 of Table I) were based upon ATA practices for conventional airframe maintenance.

2.1.7.2 Auxiliary Propulsion System

Direct maintenance labor and material costs for the auxiliary propulsion system (Item 24 of Table I) were based upon turboprop maintenance cost relationships for turboprop aircraft.

2.1.7.3 Propulsive Lift Module

2.1.7.3.1 Lift Mode

Direct maintenance labor and material costs for the propulsive lift module were based upon available maintenance labor and material cost data provided by Sikorsky Aircraft.

2.1.7.4 LTA Components

Maintenance labor requirements for the LTA components of the vehicle (Items 3, 4, 5, 6, and 7) are derived from previous large airship maintenance experience. The following manpower requirements were considered for the non-rigid configurations:

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[*] Current experience in various segments of the U. S. Helicopter industry is that large helicopters, with proper maintenance, will be operated considerably beyond 15 years.

U.L. (kg)	Personnel Required (Riggers & Mechanics) Utilization (Hours/Annum)		
	1000	2000	3000
45,372	2	4	5
90,744	3	5	6
142,468	4	6	7

Annual salaries for the riggers and mechanics were considered to be $18,000/year.

Annual material costs were estimated based upon previous airship experience. Helium replenishment costs were included in this element of the DOC and formulated upon the basis that 25% of the volume of the ship will require replacement annually. Previous airship experience suggests this to be a reasonable value to consider.

2.1.8 Maintenance Burden

Maintenance burden on the vehicle maintenance labor costs were considered to be 30% of the labor costs.

2.1.9 Flight Crew

Flight crew costs were based upon the following estimated manpower requirements (same for all non-rigid configurations):

	Personnel Utilization (Hrs/Annum)		
	1000	2000	3000
Pilot	1	2	3
Co-Pilot	1	2	3
Flight Engineer	1	2	3

The above personnel allocations result in slightly over 80 hours/-month flight time which is reasonable for a commercial non-passenger operation. Commercial (non-passenger) operators of large helicopters in the U.S. utilize flight crew members as much as 120 hours/month.

Pilot salaries were considered to be $30,000 annually with co-pilots and flight engineers considered to be $25,000 and $22,000 respectively.*

2.1.10 Fuel and Oil

The hourly DOC's presented subsequently (see Table IV) are based upon horsepower requirements for cruise at maximum gross weight at 148 km/h (80 knots). Oil costs are considered at 5% of fuel costs which is typical for a helicopter. Fuel costs were considered to be $0.75/gallon.

TABLE IV. SUMMARY OF DIRECT OPERATING COSTS FOR NON-RIGID HLA'S

Direct Operating Costs ($/HR)					
Operating Mode	U.L. (KG)	Quantity	Utilization - (Hours/Annum)		
			1000	2000	3000
Lift Mode (Cruise, Max GW, 148 km/h)	45,372	1	7738	4519	3428
		5	3938	2614	2162
		25	2854	2059	1789
	90,744	1	11060	6722	5270
		5	6680	4532	3810
		25	5160	3772	3303
	142,968	1	14825	9241	7366
		5	9730	6696	5670
		25	7785	5721	5020

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*NOTE: Pilots, Co-Pilots, and Mechanics Salaries are typical of those reported for personnel involved in large helicopter operations in U.S.

2.1.11 Direct Operating Cost Summary

Table IV summarizes the magnitude of the major elements of the DOC/hr as a function of vehicle size, quantity produced, and annual utilization.

2.2 Indirect Operating Costs (IOC)

The indirect operating costs are composed of the elements listed in Table V. These cost elements represent the non-vehicle related expenses that would be required to support a commercial HLA rental service operation. Table VI summarizes the estimated magnitude of the IOC/hr which is only a function of annual utilization.

2.3 Total Operating Cost (TOC) Summary

Table VII provides a summary of the TOC/hr (i.e. DOC/hr + IOC/hr) for the non-rigid HLA's as a function of vehicle size, quantity produced, and utilization. Table VII also provides vehicle productivity as a function of range (stage length) such that ton-mile costs can be developed. The productivity values include vehicle acceleration effects but do not include any hover allocations as this may well vary from lift to lift. The productivity values have been established using Goodyear's real time hybrid computer flight dynamics simulation. Vehicle productivity for stage lengths (ranges) greater than the data of Table VII can be determined from the range payload data of Figure 4. The data of Figure 4 were generated using a Goodyear Computer performance simulation similar to that documented in Reference 1.

The fuel system weight has not been included in the empty weight of the vehicle since the range over which the vehicle will be used will govern the amount of fuel required and accordingly the fuel system weight. With respect to Figure 4, the balance of the useful load after fuel requirements are subtracted from the vehicle useful load should be reduced by 10% of the required fuel weight to traverse a given range. The resulting value is the payload that can be transported over the range defined.

TABLE V - INDIRECT OPERATING COST ELEMENTS

1. Operations Buildings, Operations Equipment, Operations Support Vehicle, Office Equipment, Shop and Test Equipment, Fuel and Oil Storage Facilities
2. Ground Support Equipment
3. Ground Handling and Mooring Equipment
4. Mooring Circle
5. Maintenance and Maintenance Burden on Items 1 - 4
6. Real Estate Taxes
7. Utilities Expenses
8. Operations Management and Administrative Support Manager, Assistant Manager and Secretary

TABLE VI - INDIRECT OPERATING COST (IOC) SUMMARY*

	Utilization (Hrs/Annum)		
	1000	2000	3000
IOC ($/HR)	170	85	57

* For purposes of this analysis the IOC has been assumed the same for all vehicles since the IOC is insignificant compared to the DOC.

TABLE VII. SUMMARY OF BASELINE TOTAL OPERATING COSTS AND VEHICLE PRODUCTIVITY FOR NON-RIGID HLA'S (BASELINE CONFIGURATION)

Total Operating Costs ($/hr)					
Operating Mode	Useful Load (kg)	Quantity	Utilization(Hours/Annum)		
			1000	2000	3000
Lift Mode (Cruise, Max GW, 148 km/h)	45350	1	7944	4604	3825
		5	4144	2689	2219
		25	3024	2147	1846
	90700	1	11230	6807	5329
		5	6850	4617	3867
		25	5330	3834	3360
	142427	1	14995	9326	7423
		5	9900	6782	5727
		25	7955	5806	5077

Stage Length (KM)	Flight Time * (HRS)
0.46	0.94×10^{-2}
0.92	1.75×10^{-2}
1.85	2.75×10^{-2}
3.70	4.00×10^{-2}
5.55	5.19×10^{-2}
9.25	7.69×10^{-2}
18.5	14.00×10^{-2}
37.0	26.48×10^{-2}
92.5	63.98×10^{-2}
185.0	1.27
370.0	2.51
555.0	3.77
592.0	4.00

*Excludes Hover, Independent of Useful Load, One Way Trip Only

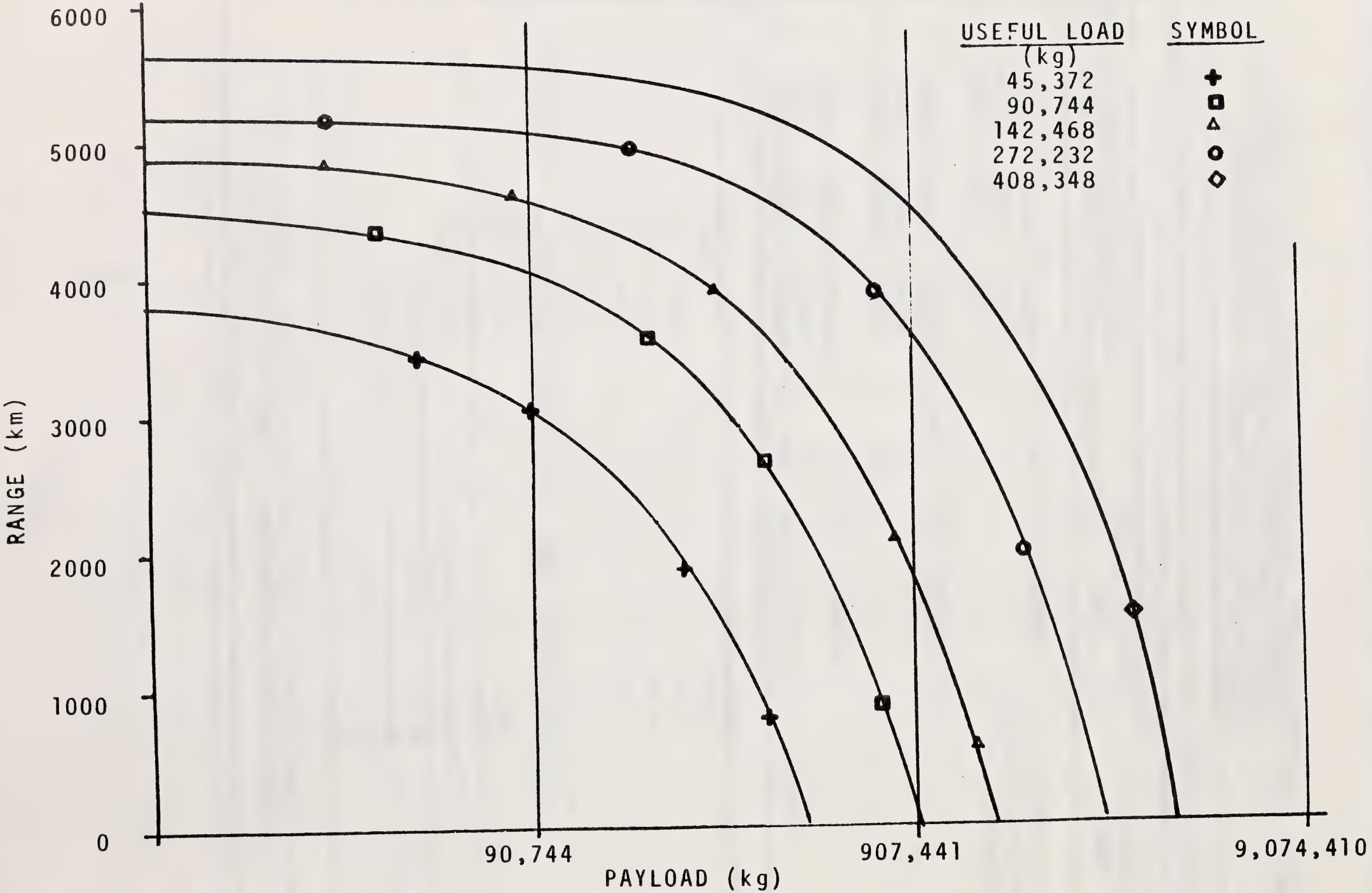

Figure 4 - Payload vs Range

Hover requirements cannot be generalized and as a result must be added in on an individual job basis. Once an estimate of the hover time requirements has been made the TOC/hr data of Table VII can be used to define the increased cost associated with this aspect of the transport scenario. Many factors will govern hover time requirements. The following is reasonably clear however, based upon large helicopter operations with externally slung loads:

1) Pre-lift planning and rigging checkout will greatly reduce hover requirements to hook up the load;

2) With proper pre-lift planning, load lift-off can proceed immediately following load hook-up;

3) There are significant learning curve effects when making repetitive lifts involving the same or similar kinds of items.

4) Hover times to place the payload will be a function of the required placement accuracy. Items not requiring any particular placement accuracy, such as moving construction equipment across a river, will require very little hover time to release the load once the vehicle/payload motion is arrested.

5) Hover times to accurately position payloads, as in the case of placing a piece of operating equipment on a foundation bolt pattern, will be considerably increased over non-precise placement requirements. This type of operation would also involve personnel on the ground to align the load (with mechanical assistance such as air tuggers) prior to final placement. This approach of using manpower to assist in final load alignment is common for helicopters used in the construction industry

and for conventional heavy and very heavy (100's of kgs) crane placements. In some cases final placement is accomplished by jacking the load into its final precise location.

Based on experience of large helicopters carrying external loads, it is anticipated that the following hover scenario would encompass a large percentage of applications not involving extreme placement accuracy:

Hover Function	Hover Time
Load Pickup	1.0 minute without payload 1.0 minute with payload
Load Release	1.0 minute with payload 1.0 minute without payload

NOTE: These times are exclusive of vehicle/payload acceleration and deceleration times which, as noted previously, have been accounted for in the productivity data of Table VII.

2.4 Total Operating Cost Sensitivity Analysis

In any new transportation system there is often difficulty in establishing the exact validity of certain of the operating cost elements. Reasonably small changes in elements that make up a significant percentage of the TOC and reasonably large changes in smaller TOC elements (if there is considerable uncertainty as to what magnitude should be assigned the smaller element) are often addressed in TOC sensitivity studies. In addition, as is the case in this study, the benefits that selected configurational or technological changes can be expected to offer to the TOC are often examined.

2.4.1 Effect of Increased RDT&E Cost

Previously it was noted that it may be necessary to produce a production prototype vehicle as a part of the RDT&E effort. It is estimated that the following total expense would result from such an activity. (Note: The demonstration vehicle is used with the helicopters being replaced with propulsive lift modules and a control car is also added.)

	Total Expense ($ x 10^6)
Disassemble Demonstration Configuration	2.5
Fabricate Four Lift Modules *	19.00
Fabricate Control Car	3.00
Reassemble Vehicle	5.00
Supporting Engineering	5.00
Ground and Flight Test	2.50
TOTAL	37.00

The increase in TOC/hr ($/hr) that this additional RDT&E results in, is shown below as a function of utilization and quantity.

Quantity of Vehicles**	Utilization (Hrs/Annum)		
	1000	2000	3000
1	3083	1542	1028
5	617	308	206
25	123	62	41

2.4.2 Effect of Acquisition Cost Variations

It is reasonable to expect that the acquisition cost data presented previously is within ±25% of the nominal values presented. The following presents the change in TOC/HR (\$/HR) accompanying vehicle acquisition costs 25% higher and 25% lower than those of Table I. The effect on spares is also included.

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* RDT&E included previously. Module costs based on U.L. of 90,744 kg (100 tons)

** Depreciation assumption same as in baseline TOC analysis

U.L. (kg)	Quantity								
	1			5			25		
	Utilization (Hrs/Annum)								
	1000	2000	3000	1000	2000	3000	1000	2000	3000
45,312	1005	503	335	420	210	140	245	123	82
90,744	1345	673	448	668	334	223	428	214	143
142,468	1738	869	579	943	471	314	635	318	212

2.4.3 Effect of Vehicle Certification Cost Increases

The increase in TOC/HR (\$/HR) associated with doubling the previously considered vehicle related certification costs of \$10 x 10^6 is shown below.

Quantity	Utilization (Hrs/Annum)		
	1000	2000	3000
1	833	417	278
5	167	83	56
25	33	17	11

NOTE: Depreciation assumption made in baseline TOC analysis has been retained

2.4.4 Effect of Increased Period of Depreciation

It was noted previously that it appears reasonable to consider depreciating the vehicle over a 15-year period as opposed to the 12 years used in the TOC analysis. The reduction in TOC/HR ($/HR) due to such an increase in the period of depreciation is shown below.

U.L. (kg)	Quantity								
	1			5			25		
	Utilization (Hr/Annum)								
	1000	2000	3000	1000	2000	3000	1000	2000	3000
45,372	802	401	267	338	169	113	198	98	66
90,744	1078	539	359	531	266	177	343	171	114
142,468	1389	694	463	752	376	251	510	255	170

2.4.5 Combined Effect of TOC Variations

The combined effect of the previously defined TOC variations is shown below normalized by the baseline TOC data of Table VII.

U.L. (kg)	Quantity	Direction of Variation of TOC	Utilization (Hrs/Annum)		
			1000	2000	3000
45,372	1	Increase	0.62	0.54	0.47
	5		0.29	0.22	0.18
	25		0.13	0.09	0.07
90,744	1		0.47	0.39	0.33
	5		0.21	0.16	0.13
	25		0.11	0.08	0.06
142,468	1		0.38	0.30	0.25
	5		0.17	0.13	0.10
	25		0.10	0.07	0.05
45,372	1	Decrease	0.23	0.20	0.17
	5		0.18	0.14	0.11
	25		0.15	0.10	0.08
90,744	1		0.22	0.18	0.15
	5		0.18	0.13	0.09
	25		0.14	0.10	0.08
142,468	1		0.21	0.17	0.14
	5		0.17	0.12	0.10
	25		0.14	0.10	0.08

Thus from the above tabulation it can be seen that for any reasonable number of vehicles, used a reasonable number of hours/year, that the TOC is not expected to increase from the baseline more than 10 to 15%. A reasonable lower limit for this same situation appears to be on the order of 10-15% below the baseline TOC.

2.4.6 Configurational Change Effects

The only configurational changes considered herein is the economic benefit to be gained from a rotor system capable of equal amounts of positive and negative thrust. This configurational change can reduce the percentage of the payload carried by the rotors from 100% to 50%. Buoyancy is then used to carry the remaining 50% of the payload. This HLA configuration is thus aerostatically light without payload and the rotors are used to push down to offset the buoyancy and return the ship to a neutrally buoyant condition. Certain operational and design complexities are introduced as a result of this configurational change. Additional research and development costs may also be required. The increased costs associated with these items are not addressed herein. The following presents a rough estimate of the favorable impact on the TOC/HR ($/HR) that this configurational change could be expected to have for a vehicle with a useful load of 90,744 kg (100 tons).

U.L. (kg)	Configuration	Quantity								
		1			5			25		
		Utilization (hrs/annum)								
		1000	2000	3000	1000	2000	3000	1000	2000	3000
90,744	Alternate-$/hr	8996	5075	3755	4836	2995	2513	3486	2320	1919
90,744	Baseline -$/hr	11230	6807	5329	6850	4617	3867	5330	3857	3360
Ratio of TOC's		0.80	0.75	0.70	0.71	0.65	0.65	0.65	0.60	0.57

From the above ratios it is apparent that an approximate reduction in $TOC/HR of 30-40% can be expected. Although not confirmed at this point, it is expected that the productivity at shorter stage lengths of the alternate configuration may approach that of the baseline configuration. The reason this is not obvious is that the alternate configuration has less installed power and a considerably larger hull than the baseline configuration of equal useful load. This point should be explored before any TOC/kg m comparisons are made.

The unequivocal benefit of negative as well as positive rotor thrust is the useful load growth capability that it offers. It is currently anticipated that extremely large HLA configurations (several hundred kg) would in all probability use such a rotor system.

It should be noted that although there is no significant difficulty in designing a rotor system that can create equal amounts of positive and negative thrust, this does mean that the rotor blade would not be twisted. The lack of twist in the blade will lead to some inefficiency (i.e., more power required per unit thrust) perhaps on the order of 10%. This inefficiency is not accounted for in the above TOC values.

3.0 TOTAL OPERATING COSTS FOR RIGID HLA'S

The methodology used in the TOC analysis is the same as in the nonrigid analysis and as a result only salient features are presented herein.

3.1 Direct Operating Costs for Rigid HLA's

3.1.1 Flyaway Costs

Vehicle component and assembly costs were developed for the component groups listed in Table VIII. The costs of the component groups summarized in Table VIII were developed from CER's in a manner similar

TABLE VIII. VEHICLE COMPONENTS AND ASSEMBLY COSTS (10^6 DOLLARS) VS USEFUL LOAD AND QUANTITY (RIGIDS)

Useful Load in kg	272,232			408,348		
Number of Units	1	5	25	1	5	25
1 Outriggers	14.2492	50.1631	176.5955	20.2992	71.4617	251.5753
2 Main Frames	18.0329	63.4834	223.4882	26.8070	94.3719	332.2288
3 Intermediate Frames	3.7141	13.0752	46.0302	5.7857	20.3681	71.7043
4 Shear Wires	-	-	-	-	-	-
5 Longitudinals	5.8226	20.4980	72.1616	9.0016	31.6894	111.5601
6 Keel	3.2625	11.4854	40.4333	4.4508	15.6687	55.1604
7 Outer Cover	-	-	-	-	-	-
8 Outer Cover Wires	-	-	-	-	-	-
9 Gas Bag Wire and Netting	-	-	-	-	-	-
10 Gas Cells (Sum of Items 4,7,8,9,10)	11.2066	39.4519	138.8874	16.0518	56.5091	198.9357
11 Gas Valves	.0397	.1360	.4663	.0633	.2171	.7444
12 Stern and Bow	-	-	-	-	-	-
13 Miscellaneous Gas Cells and Valves (Sum of Items 12 & 13)	.3286	1.1266	3.8622	.5246	1.7985	6.1660
14 Miscellaneous Hull Weight	1.1649	4.1009	14.4370	1.6668	5.8678	20.6573
15 Corridors	.5920	2.0840	7.3366	.6986	2.4594	8.6581
16 Axial Girder	.3331	1.1726	4.1281	.5573	1.9618	6.9063
17 Control Car	.8922	2.8155	8.8840	1.0427	3.2902	10.3819
18 Landing Gear	4.7190	15.6174	52.4270	7.4962	24.8090	83.2834
19 Module Structure	3.7584	11.8596	37.4225	5.0203	15.8416	49.9876
20 Flight Controls	.8049	3.4840	15.0806	1.1643	5.0395	21.8138
21 Equipment	.6004	2.5990	11.2499	.9006	3.8985	16.8747
22 Rotor System	3.7071	18.5356	92.6780	5.5607	27.8034	139.0170
23 Drive System	3.8197	19.0985	95.4927	5.5883	27.9413	139.7066
24 Engines	7.0798	23.5718	77.3120	9.3747	31.0894	101.3361
25 Engine Installation	.6473	2.0424	6.4448	.8488	2.6782	8.4511
26 Instruments - Navigation	.0245	.1223	.6115	.0245	.1223	.6115
27 Instr. -Eng., Transm., Hydr.	.1536	.7678	3.8391	.2304	1.1523	5.7615
28 Misc. Instr., Auto Pilot, F.B.Y.	.0256	.1278	.6389	.0256	.1278	.6389
29 Electronics	.0400	.1731	.7495	.0400	.1731	.7495
30 Furnishings	.0134	.0580	.2511	.0134	.0580	.2511
31 Air Conditioning	.0675	.2922	1.2647	.0675	.2922	1.2647
32 Empennage	4.9014	17.2550	60.7448	7.1205	25.0672	88.2469
33 Aux Propulsion	2.9728	10.4655	36.8428	3.7088	13.0567	45.9649
34 FBW Control System, AFCS, IMU, SAS, Stick Force Feel Sys, Emp Act., PHS,	.4600	2.3000	11.5000	.4600	2.3000	11.5000
35 Assembly of Vehicle	23.3585	84.4907	310.3151	33.6485	121.7786	447.5345
Total	116.7923	422.4533	1551.5754	168.2425	608.8928	2237.6724

to the non-rigid configurations. Table IX summarizes the component weights for the vehicle useful loads considered, i.e., 27,223 and 40,835 kg (300 and 450 tons). These weights were generated from the WER's of Reference 1 with modifications to include recent changes to the configuration. In comparison to the non-rigid costs of Table I,

TABLE IX. RIGID HEAVY LIFT AIRSHIP COMPONENT WEIGHTS (KG)

Item No.			
	Useful Load - (kg)	272,232	408,348
	Volume x 10^{-6} (	0.296	0.48
	No. of Rotors	8	12
	Rotor Diameter - (m)	29.8	29.8
	Buoyant Lift - (kg)	279,188	455,518
1	Outriggers	43,568	67,565
2	Main Frames	51,203	85,917
3	Intermediate Frames	6,508	11,608
4	Shear Wires	6,228	10,717
5	Longitudinals	11,705	20,671
6	Keel	5,495	8,242
7	Outer Cover	4,877	6,634
8	Outer Cover Wires	538	735
9	Gas Bag Wire and Netting	2,475	3,951
10	Gas Cells	13,977	21,950
11	Gas Valves	1,235	1,971
12	Stern and Bow	210	335
13	Miscellaneous Gas Cells and Valves	535	855
14	Miscellaneous Hull Weight	1,432	2,286
15	Corridors	591	735
16	Axial Girder	279	547
17	Control Car	680	680
18	Landing Gear	33,207	52,748
19	Module Structure	11,726	17,589
20	Flight Controls	2,694	4,041
21	Equipment	2,082	3,123
22	Rotor System	22,968	34,453
23	Drive System	28,598	42,569
24	Engines	5,637	8,273
25	Engine Installation	1,409	2,068
26	Instruments - Navigation	39	39
27	Instr. - Eng., Transm., Hydr.	605	908
28	Misc. Instr., Auto PILOT F.B.Y.	101	101
29	Electronics	121	121
30	Furnishings	84	84
31	Air Conditioning	141	141
32	Empennage	9,892	16,107
33	Aux. Propulsion	3,391	4,526
34	FBW Control System, AFCS, IMU, SAS, Stick Force Feel System, PHS, Empennage Acuators	907	907
35	Crew	272	272
36	Empty Weight	274,410	433,469

the only significant difference in the approach used to estimate the vehicle costs of Table VIII is in the area of the aerostat. In the case of the rigid aerostat components, the conventional transport aircraft fuselage CER's of Reference 3 were used.

3.1.2 Vehicle Development and Certification Costs

Whereas reasonably modest development costs are anticipated in the case of the smaller non-rigid HLA's, considerable development is anticipated in the case of the rigid configurations. The development requirements (see Table X) are primarily in the area of the aerostat. There have been no rigid airships designed, built or flown for forty years. It is considered likely that an interim size vehicle would be

TABLE X. TOTAL VEHICLE COSTS (MILLIONS OF DOLLARS) - Rigid HLA'S

Cost Element	Quantity					
	1		5		25	
	U. L. (kg)					
	27,223	40,835	27,223	40,835	27,223	40,835
1. Vehicle Component Fabrication and Assy	116.8	168.2	422.5	608.9	1551.6	2237.7
2. Vehicle RDT&D and Certification	525	525	525	525	525	525
3. Manufacturing Facilities (Vehicle Assy & Erection)	5*	5*	17.5*	17.5*	52**	52**
TOTAL	646.8	698.2	965.0	1151.4	2128.6	2814.7
4. Total Cost/Vehicle	646.8	698.2	193	230.3	85.1	112.6

*Refurbish existing facilities. Includes ground support equipment required at point of manufacture.

**Refurbish existing facilities plus fabricate new facilities. Includes ground support equipment at point of manufacture.

mandatory before the development of either a 27,223 and 40,835 kg (300 or 450-ton) useful load vehicle would be a prudent step.

The basic philosophy (see Reference 1) in the case of the rotor module was to simply increase the number of rotor systems once the rotor system reached the size limit of today's technology. It is reasonable to anticipate that the very large HLA's would utilize rotors that develop both positive and negative thrust. This approach has not been considered herein, however, the potential benefits of this type of configurational change were briefly explored in Section 2.4.6. As noted in Section 2.4.6, the rotor system design to accomplish this is not particularly challenging but the size of the aerostat does increase substantially. Thus, the above discussion on interim sized vehicles is amplified.

3.1.3 Total Aircraft Costs

Total aircraft costs are summarized in Table X. Development and certification costs were amortized over the various quantities of vehicles considered. Manufacturing facilities costs for vehicle assembly and erection and ground support equipment as the point of manufacture have been included.

3.1.4 Insurance Costs

The same insurance rate as used in the case of the non-rigid configuration has been applied to the rigid configuration.

3.1.5 Vehicle Depreciation

The same assumption has been used for the rigid configuration as for the non-rigid configuration.

3.1.6 Direct Maintenance

The same approach has been used as in the case of the non-rigid configurations with one exception. In the case of the rigid configurations, the ATA approach for defining fuselage maintenance costs has been used for the airship hull.

3.1.7 Maintenance Burden

The assumption for the rigid configurations is the same as for the non-rigid configurations.

3.1.8 Flight Crew

Flight crew requirements have been considered the same for all vehicles (rigids and non-rigids). This is obviously simplistic as larger vehicles will intuitively have larger crews. The correct assumption on crew size, however, leads to an insignificant change in TOC.

3.1.9 Fuel and Oil

Calculations of the fuel and oil costs was approached on the same basis as those of the non-rigid configurations.

3.2 Indirect Operating Costs

The indirect operating cost elements for the rigid HLA's are the same as those of Table V for the non-rigids. The hourly indirect costs are estimated to be $1,000, $500 and $333 for 1000, 2000 and 3000 hours per annum utilization, respectively, for the rigid HLA's.

3.3 Total Operating Costs Summary

Table XI provides a summary of the TOC/HR for the rigid HLA's as a function of vehicle size, quantity produced, and utilization for both the lift and ferry modes. Table XI also summarizes expected vehicle productivity as a function of stage length. Again, the productivity values vehicle/payload acceleration affects but do not include any hover time allocations. These must be addressed separately as in the case of the non-rigids of the non-rigids as discussed previously in Section 2.3.

TABLE XI. SUMMARY OF BASELINE TOTAL OPERATING AND PRODUCTIVITY FOR RIGID HLA'S

Total Operating Costs ($/HR)

Operating Mode	U.L. (kg)	Quantity	Utilization - Hours/Annum)		
			1000	2000	3000
Lift Mode (Cruise, Max GW, 148 km/h)	27,223	1	77698	42475	30733
		5	29376	18314	14626
		25	17836	12544	10779
	40,835	1	87033	48908	36198
		5	37153	23968	19571
		25	24543	17663	15368

Stage Length (KM)	Flight Time * (HRS)
0.46	0.94×10^{-2}
0.92	1.75×10^{-2}
1.85	2.75×10^{-2}
3.70	4.00×10^{-2}
5.55	5.19×10^{-2}
9.25	7.69×10^{-2}
18.50	14.00×10^{-2}
37.00	26.48×10^{-2}
92.50	63.98×10^{-2}
185.00	1.27
370.00	2.51
555.00	3.77
592.00	4.00

*Excludes Hover, Independent of Useful Load, One Way Trip Only

3.4 Total Operating Cost Comparison

Although not presented herein, the total operating costs per available ton mile decrease slightly with increasing size for each type of configuration (non-rigid and rigid). At the point where the rigid construction is adopted there is a step increase in TOC/ kg-km (ton-mile) because of the significant RDT&E costs that are anticipated in the case of the rigid configuration.

It should be noted that the decrease in TOC/kg-km (ton-mile) with increasing size within each class of construction is a trend evident in conventional heavier-than-air craft. It primarily results from a reduction in vehicle acquisition costs on an empty weight basis as size increases.

REFERENCES

1. Development of Weight Estimating Relationships for Rigid and Non-Rigid Heavy Lift Airships; Goodyear Aerospace Corporation; NASA CR151976, March 1977

2. A Simplified Method for Forecasting Rotary Wing Aircraft to Final Report; Sikorsky Engineering Report SER-50466, 1967

3. Parametric Study of Transport Aircraft Systems Cost and Weight, Science Applications, Inc.; NASA CR-151970, April 1977

4. Feasibility Study of Modern Airships, Phase II, Volume I; Goodyear Aerospace Corporation; NASA CR-151917; September 1976

AN-9103-D
SUPERSEDING
AN-9103-C
FOR AIRSHIPS

NAME ____________________
DATE ____________________

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MODEL ZPG-X-3W
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APPENDIX C
ZPG-X-3W

GROUP WEIGHT STATEMENT

ESTIMATED ~~CALCULATED, ACTUAL~~

(Cross out those not applicable)

CONTRACT NO. ____________________

AIRSHIP, GOVERNMENT NO. ____________________

AIRSHIP, CONTRACTOR NO. ____________________

MANUFACTURED BY GOODYEAR AEROSPACE CORPORATION

		MAIN	**AUXILIARY**
ENGINE	**MANUFACTURED BY**	AVCO LYCOMING	ALLISON
	MODEL	LTC 1K-4C	250-20B
	NO.	2	2
PROPELLER	**MANUFACTURED BY**		
	DESIGN NO.		
	NO.	2	1

NAME ____________________
DATE ____________________

GROUP WEIGHT STATEMENT
WEIGHT EMPTY

PAGE 2
MODEL ZPG-X-3W
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1	ENVELOPE GROUP						19200
2	ENVELOPE					10040	
3	BALLONETS					2200	
4	FORWARD				550		
5	CENTER				1100		
6	AFT				550		
7	AIR LINES					510	
8	CAR SUSPENSION					1700	
9	INSIDE				1020		
10	OUTSIDE				680		
11	BOW STIFFENING AND MOORING					1400	
12	MOORING CONE, SPINDLE, NOSE CONE, TAPES				480		
13	BATTENS				680		
14	BATTEN ATTACHMENT				220		
15	NOSE STIFFENING COVER				20		
16	FIN CATENARIES OR SUSPENSION PROVISIONS					1000	
17	CAR FAIRING					600	
18	MISCELLANEOUS					1000	
19	MAIN PROPULSION PROVISIONS					750	
20							
21	TAIL GROUP						3800
22	FINS - UPPER (2)					1350	
23	FINS - LOWER (2)					1350	
24	FINS - HORIZONTAL						
25	RUDDER OR RUDDEVATORS (4)					750	
26	ELEVATORS						
27	FIN SUSPENSION					350	
28							
29	CAR GROUP						5500
30	BASIC STRUCTURE					4270	
31	SECONDARY STRUCTURE - CAR					650	
32	- DOORS, PANELS, MISCELLANEOUS					580	
33							
34	ALIGHTING GEAR GROUP (TYPE: BICYCLE)						1200
35		LOCATION	WHEELS, BRAKES,	STRUCTURE	CONTROLS		
36			TIRES, TUBES, AIR				
37	MAIN	CAR				900	
38	NOSE	CAR				300	
39							
40							
41	PRESSURE GROUP						2400
42	PRESSURE SYSTEM (LESS CONTROLS)					1800	
43	CONTROLS					600	
44							
45	ENGINE SECTION AND NACELLE GROUP (MAIN)						550
46	ENGINE SECTION					300	
47	NACELLES					200	
48	DOORS, PANELS, MISCELLANEOUS					50	
49							
50	STERN GROUP						1600
51	SURFACES AND SUPPORTS					700	
52.	TAIL CONE AND BATTENS					600	
53	ENGINE SECTION AND NACELLES					300	
54							
55	OUTRIGGER GROUP (WING)						2500
56							
57	TOTAL STRUCTURE TO BE BROUGHT FORWARD						36750

NAME ____________
DATE ____________

GROUP WEIGHT STATEMENT
WEIGHT EMPTY

PAGE 3
MODEL ZPG-X-3W
REPORT ____________

		AUXILIARY-STERN		MAIN		
1	BALLAST GROUP					
2	TANKS AND SUPPORTS					250
3	PIPING, VALVES, PUMPS, ETC.				–	
4	WATER RECOVERY SYSTEM				250	
5						
6	PROPULSION GROUP					
7	ENGINE INSTALLATION					7700
8	ACCESSORY DRIVES		550		1500	
9	AIR INDUCTION SYSTEM		150		100	
10	EXHAUST SYSTEM		25		50	
11	COOLING SYSTEM		50		100	
12	LUBRICATING SYSTEM					
13	TANKS		95		250	
14	COOLING INSTALLATION	20		50		
15	PLUMBING, ETC.	50		100		
16	FUEL SYSTEM	25		100		
17	TANKS		150		2200	
18	PLUMBING, ETC.	50		1000		
19	TRANSMISSION SYSTEM	100		1200		
20	ENGINE CONTROLS					
21	STARTING SYSTEM		200		500	
22	PROPELLER INSTALLATION		50		80	
23			500		1150	
24	AUXILIARY POWER PLANT GROUP					
25						750
26	INSTRUMENTS AND NAVIGATIONAL EQUIPMENT GROUP					
27						350
28	HYDRAULIC AND PNEUMATIC GROUP					
29						450
30	ELECTRICAL GROUP					
31						1000
32	ELECTRONICS GROUP					
33	GOVERNMENT FURNISHED EQUIPMENT					
34	CONTRACTOR INSTALLATIONS					
35						
36	ARMAMENT GROUP					
37						
38	FURNISHINGS AND EQUIPMENT GROUP					
39	ACCOMMODATIONS FOR PERSONNEL					1100
40	MISCELLANEOUS EQUIPMENT				350	
41	FURNISHINGS				100	
42	EMERGENCY EQUIPMENT				400	
43					250	
44	AIR CONDITIONING AND ANTI-ICING EQUIPMENT GROUP					
45	AIR CONDITIONING					700
46	ANTI-ICING				650	
47					50	
48	AUXILIARY GEAR GROUP					
49	WINCH AND CONTROLS					800
50	HANDLING LINES				600	
51					200	
52	SURFACE CONTROL GROUP					
53	COCKPIT CONTROLS					1250
54	SYSTEM CONTROLS				350	
55					150	
56	TOTAL FROM PAGE 2				750	
57	WEIGHT EMPTY					36750
						51100

NAME ____________
DATE ____________

GROUP WEIGHT STATEMENT
USEFUL LOAD AND GROSS WEIGHT

PAGE 4
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REPORT ____________

1 2	LOAD CONDITION				
3	CREW (NO. 18)				
4					
5	PASSENGERS (NO.)				
6					
7	FUEL				
8	INTERNAL				
9	EXTERNAL				
10	SLIP TANKS				
11	UNUSABLE				
12					
13	OIL				
14	ENGINE				
15	TRAPPED IN SYSTEM				
16					
17	FUEL TANKS (EXTERNAL)				
18					
19					
20					
21	BAGGAGE				
22					
23					
24					
25	CARGO				
26					
27					
28					
29	ARMAMENT				
30	MISSILES				
31	BOMBS				
32	TORPEDO				
33					
34	BOMB RACKS AND SWAY BRACING				
35					
36					
37					
38	EQUIPMENT				
39	PYROTECHNICS				
40	PHOTOGRAPHIC				
41	CREW PROVISONS				
42	MISCELLANEOUS				
43	VARIABLE PAYLOAD				
44					
45					
46	ELECTRONICS - FIXED PAYLOAD				
47					
48					
49					
50	BALLAST (WATER)				
51					
52					
53	USEFUL LOAD				45400
54					
55	WEIGHT EMPTY				51100
56					
57	GROSS WEIGHT				96500